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Process Design Manual Municipal Sludge Landfills

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Jim Walsh

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SCS Engineers
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16. ABSTRACT

The primary objective of this manual is to provide general guidance and a source of information to be used in the planning, design, and operation of a landfill receiving municipal wastewater treatment plant sludge. Accordingly, typical procedures, case studies, and examples are presented which are intended to serve as aids to the user.

Major alternative sludge landfilling methods are identified and described. Guidance is given on the selection of the landfilling method which is best suited for a given combination of sludge characteristics and site conditions. For each landfilling method, the following features are addressed: public participation program, site selection, design, operation, monitoring, completed site, management, and costs.

The information contained in the manual is intended for use by wastewater authorities, public and private operators, environmental planners, and consulting engineers. Because of the variety of user backgrounds and needs, the manual has been organized to allow the user to locate particular information as easily as possible.

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a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
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Municipal sludge management is perhaps one of the most visible and complex problems facing wastewater treatment authorities today. The combination of greatly increased sludge volumes and the narrowing of formerly used disposal options (such as ocean dumping) compounds this problem. Congress, in enacting the Resource Conservation and Recovery Act, and the Clean Water Act, acknowledged its concern over the disposal of residuals resulting from the cleanup of our environment. A common goal of these two acts is the conservation of natural resources and energy through reuse waste materials.

EPA is committed to a residuals management program that will not only protect public health and the environment but will maximize the use of waste materials in beneficial ways. Specifically, management technologies which recycle or reuse municipal sludges and thereby contribute to energy and resource conservation are actively encouraged.

Unfortunately, beneficial utilization of sludge is not always practicable or economical. Therefore, sanitary landfilling of municipal sludge will continue as a major disposal option. It is the purpose of this manual to provide the engineering community, related industry, and local government with a new source of information for the planning, design and operation of municipal sludge landfills. It has been written to provide design and operational guidance to sanitary landfill operators and information to assist in the preparation of sewage treatment plant construction grant applications.

The usefulness of this manual will be further enhanced with the promulgation of sludge utilization and disposal guidelines that are now being developed under the authority of Section 405 of the Clean Water Act. The manual will provide publicly owned treatment works with the detailed technical information needed to comply with the landfilling portions of those guidelines.

for Steffen Plehn
Deputy Assistant Administrator
for Solid Waste

John T Rhett
John T. Rhett
Deputy Assistant Administrator
for Water Program Operations

Samuel R Rondberg
Samuel Rondberg
Acting Director
Office of Research
Program Management

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MUNICIPAL SLUDGE LANDFILLS

U.S. ENVIRONMENTAL PROTECTION AGENCY

Environmental Research Information Center
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CONTRACTOR-AUTHORS: SCS Engineers

Direction: E. T. Conrad and R. Stearns, Principals

Senior Author: J. Walsh, Project Manager

Staff Authors: J. Atcheson, E. Bowring, W. Coppel, R. Lofy, R. Morrison, D. Pearson, T. Phung, and D. Ross

Production Staff: L. Fauvie and C. Heglar

CONTRACT SUPERVISORS: U.S. Environmental Protection Agency

Project Officer: J. Perry, EPA Office of Solid Waste

Reviewers: J. E. Smith, Jr. and D. J. Lussier, EPA Environmental Research Information Center

REVIEW COMMITTEE

M. Adams and M. Derdeyn, Browning-Ferris Industries
R. Bardwell, Gellman Research Associates
R. Bastian, EPA Office of Water Program Operations
D. Blackman, State of New York
W. Bucciarelli, State of Pennsylvania
A. Day, State of Maine
R. Domenowske, Municipality of Metropolitan Seattle
P. Dunlap, SCA Services
B. Fowler, Waste Management, Inc.
A. Geswein, EPA Office of Solid Waste
E. Higgins, EPA Office of Solid Waste
G. Lukasik, North Shore Sanitary District
R. Van Heuit, Los Angeles County Sanitation District
R. Williams, State of Georgia

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FOREWORD

The formation of the United States Environmental Protection Agency marked a new era of environmental awareness in America. This Agency's goals are national in scope and encompass broad responsibility in the areas of air and water pollution, solid wastes, pesticides, and radiation. A vital part of EPA's national pollution control effort is the constant development and dissemination of new technology.

It is now clear that only the most effective design and operation of pollution control facilities, using the latest available techniques, will be adequate to ensure continued protection of the Nation's resources. It is essential that this new technology be incorporated into the contemporary design of pollution control facilities to achieve maximum benefit of our pollution control expenditures.

The purpose of this manual is to provide the engineering community and related industry a new source of information to be used in the planning, design and operation of municipal sludge landfills. It is recognized that there are a number of design manuals, manuals of standard practice, and design guidelines currently available. It is the intent of this manual to supplement this existing body of knowledge.

Two major information sources were used to compile data for inclusion in this manual. The first was a comprehensive literature review that included publications, conference proceedings, unpublished information from research projects, and product literature from equipment manufacturers. The second was case study site investigations which included a thorough inspection of on-site operating procedures and interviews with landfill operating and management personnel.

A committee of experts in the planning, design, and operation of sludge landfills was convened to review and finalize the manual outline; to identify the needs of the potential users; and to discuss the material to be included in the manual. Interim manual drafts were reviewed by EPA personnel and the above-mentioned committee.

This manual is one of several available from Technology Transfer to describe technological advances and new information. Future editions will be issued as warranted by advancing state-of-the-art to include new data as they become available, and to revise design criteria as additional full-scale operational information is generated.

Companion publications describing alternative sludge treatment and disposal methods are available in the form of Technology Transfer Seminar Handouts. They may be obtained by writing:

U. S. EPA
ERIC
26 W. St. Clair
Cincinnati, Ohio 45268

CHAPTER 1

INTRODUCTION

1.1 Sludge Disposal Alternatives

Wastewater authorities today are faced with a dilemma. As improved treatment technologies, more stringent regulatory requirements, and increasing flows all produce greater quantities of sludge, phased prohibition of ocean dumping, other regulatory constraints, and spiraling costs are combining to limit sludge disposal alternatives. Wastewater authorities are effectively limited to two methods of disposal:

1. Conversion processes (incineration, pyrolysis, and composting)
2. Land disposal (landspreading and landfilling)

Many communities have found conversion processes to be quite costly. Specifically, incineration is becoming more costly because of energy cost escalations and stringent air emission regulations. Whereas sludge incineration appeared quite attractive when capital costs were financed with Federal and State funds, operating expenses are now a burden for the local taxpayer. For this reason some communities have closed their incinerators and implemented other disposal alternatives.

Composting, of course, produces a beneficial substance which can be used as a soil conditioner by farmers, homeowners, highway departments, and park authorities. Initial pilot and plant scale operations with sludge composting have been favorable. However, composting is labor intensive and the cost-effectiveness of the operation is keyed to the market for the resulting soil conditioner.

As noted above, landspreading and landfilling are generally recognized as the two types of land disposal for sludge. Landspreading is a land-intensive disposal option and its use may be limited by the lack of available open land areas in many developed areas. Also some sludges, because of their chemical constituents, may not be suitable for landspreading. For these reasons, landfilling of sludges will continue to be a viable disposal alternative.

1.2 Sludge Landfills and Solid Waste Disposal Facility Classification Criteria

Sludge landfilling generally can be defined as the burying of sludge; i.e., the application of sludge to the land and subsequent interment by applying a layer of cover soil atop the sludge. To be defined as a landfill, the thickness of the soil cover must be greater than the depth of the plow zone. For this reason, subsurface injection of sludge is a landspreading, not a landfilling operation.

Classification Criteria for Solid Waste Disposal Facilities are being promulgated by EPA. These criteria establish the minimum performance standards that solid waste land disposal facilities shall meet so as to be classified as posing no reasonable probability of adverse affects on health or the environment. For all solid waste disposal facilities, the following areas are included:

1. Environmentally sensitive areas
    - a. Wetlands
    - b. Floodplains
    - c. Permafrost areas
    - d. Critical habitats of endangered species
    - e. Recharge zones of sole source aquifers
2. Surface water
3. Groundwater
4. Air
5. Application on land used for the production of food chain crops
6. Disease vectors
7. Safety
    - a. Explosive gases
    - b. Toxic or asphyxiating gases
    - c. Fires
    - d. Bird hazards to aircraft
    - e. Uncontrolled access

Many of the topics considered in the proposed Criteria are addressed by State and local regulations. In some cases State and local regulations will address concerns that are not covered by the Criteria. In all cases, the State and local requirements should be consulted.

1.3 Objectives of Manual

The primary objective of this manual is to provide general guidance and a source of information to be used in the planning, design, and operation of a landfill receiving municipal wastewater treatment plant sludge. Accordingly, typical procedures, case studies, and examples are presented which are intended to serve as aids to the user.

Major alternative sludge landfilling methods are identified and described. Guidance is given on the selection of the landfilling method which is best suited for a given combination of sludge characteristics and site conditions. For each landfilling method, the following features are addressed: public participation program, site selection, design, operation, monitoring, completed site, management, and costs.

1.4 Scope of Manual

The manual represents the current state-of-the-art with respect to municipal sludge landfills. Available sources of information (both in the literature and in operating practice) were investigated and incorporated into the manual. Where specific design criteria may seem lacking, it is due to the limited research effort which has been performed on sludge landfills, in comparison to other disposal options (e.g., landspreading). The variability of regulatory requirements from state-to-state and year-to-year would have made such design criteria difficult to compile and easily outdated. Accordingly, design criteria and operational procedures for existing sludge landfills were sometimes included in lieu of prescribing these criteria and procedures for new sites. This manual is not intended to serve as a textbook or to supplant engineering judgement. On an actual site design, sound engineering judgement should be exercised either to verify the design criteria (if these are included in this manual) or initially determine the criteria (if these are not included).

Although this manual is in general accordance with the Classification Criteria for Solid Waste Disposal Facilties, it is not intended to define policy on municipal sludge landfills. Further, following the design criteria and operating procedures of this manual will not guarantee compliance with the Criteria. However, the manual is intended to present state-of-the-art technology and adherence of a sludge landfill to the

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This manual is directed at the disposal of sludges generated by municipal wastewater treatment plants. Sludges generated by industrial wastewater treatment plants are not necessarily within the scope of this manual. However, many industrial sludges are similar in composition to municipal sludges and may be handled similarly. Under these circumstances, this manual may be equally useful for industrial sludge landfills. Generally, however, if industrial sludges contain significant concentrations of hazardous constituents, outside references, and advice should be sought for procedures specific to the handling of such hazardous wastes.

The manual has been confined to identifying and describing three major operational methods. The sludge-only landfilling methods of trench and area fill are given emphasis. Codisposal landfilling of sludge and refuse is also addressed.

1.5 Use of Manual

The information contained in the manual is intended for use by wastewater authorities, public and private operators, environmental planners, and consulting engineers. Because of the variety of user backgrounds and needs, the manual has been organized to allow the user to locate particular information as easily as possible.

Most users have information needs in one particular phase of sludge landfilling. Accordingly, most of the chapters of this manual have been established to trace the chronological development of a landfill. Other chapters are for general information purposes. As shown in Figure 1-1, many of the tasks outlined are concurrent. While every attempt has been made to make each chapter self-contained, the manual is best used in its entirety.

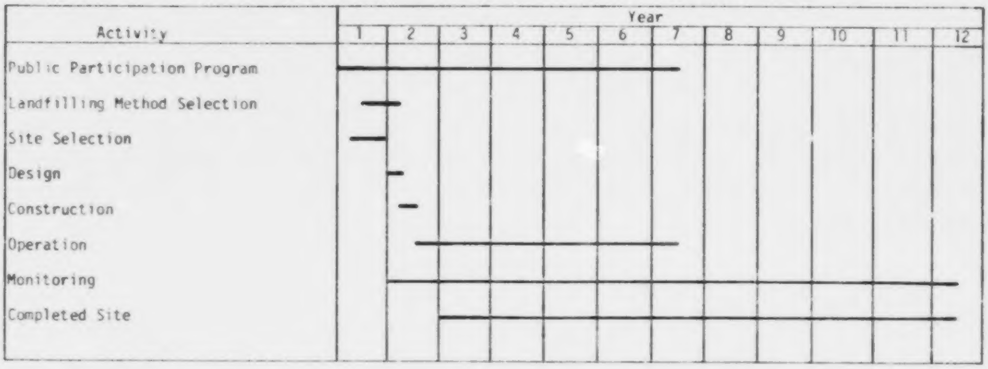
The following brief chapter descriptions are provided as an introduction to the organization of the manual.

Chapter 2 - Public Participation Program

The objectives of a public participation program as well as its advantages and disadvantages are discussed. The design of a public

FIGURE 1-1

SUGGESTED TIMING OF PLANNING, DESIGN, AND OPERATION ACTIVITIES FOR SAMPLE LANDFILL WITH FIVE YEAR LIFE



participation program including a schedule of activities and a list of target groups for a public participation programs is included.

Chapter 3 - Sludge Characteristics and Landfilling Methods
General information on the sources, treatment, and characteristics of municipal sludge is presented. Major alternative sludge landfilling methods (and sub-methods) are defined and described. Guidance is given on the selection of the landfilling method best suited for a given set of sludge characteristics and site conditions.

Chapter 4 - Site Selection
Major criteria that affect the selection of a landfill site are identified. A general procedure for applying these criteria to a site selection is outlined. A specific example of a site selection process using a scoring system is introduced.

Chapter 5 - Design
Sources of information needed for designing a sludge landfill are detailed. Methodologies for performing designs and submitting design documents are outlined. Design features for each landfilling method are discussed. Environmental factors are described and appropriate control mechanisms are detailed, including control of leachate and gas.

Chapter 6 - Operation
Operational procedures for each landfilling method are described, including equipment and personnel requirements. Illustrations and brief descriptions of specific landfills demonstrating alternative landfilling methods are included.

Chapter 7 - Monitoring
Concepts for conducting groundwater, surface water, and gas monitoring are presented. Sample point location, well construction, sampling techniques, analytical methods, and data interpretation are discussed.

Chapter 8 - Completed Site
Procedures for site closure are outlined. Characteristics of a completed sludge landfill and uses of completed sites are discussed.

Chapter 9 - Management and Costs
Management functions are discussed. Typical costs for existing sludge landfills are presented. A comparison of costs for the various landfilling methods is shown.

Chapter 10 - Design Examples
Using given sludge characteristics and site conditions, design features are outlined and operational procedures established for three sludge landfills. These three examples cover the full range of large to small treatment facilities.

Chapter 11 - Case Studies
Detailed descriptions of the site selection, public participation,design, operation, and monitoring programs at five landfills are presented. In addition, costs for the operations are discussed. Summary tables of design, operation, and cost data for 22 sites are presented.

CHAPTER 2

PUBLIC PARTICIPATION PROGRAM

2.1 Introduction

Traditionally, little effort has been made to involve the public in engineering projects. Where exceptions exist, the emphasis has been on developing public acceptance programs. The term "acceptance", however, precisely conveys the kind of role the public was expected to play in these programs--that of a passive recipient of information geared to win general approval so that the engineer could proceed with the best possible technical design. But this type of approach will no longer work. The public expects to play an active part in environmental decision-making as both the Clean Water Act of 1977 (PL 95-217) and the Resource Conservation and Recovery Act of 1976 (PL 94-580) mandate public involvement mechanisms and activities. Therefore, the purpose of a public participation program (PPP) in the establishment of sludge landfills is to give the public a participatory role throughout planning, design, and operation. This chapter details the objectives of a public participation program, its advantages and disadvantages, PPP participants, the design of a program, timing of public participation activities, and areas of public concern in sludge landfilling.

2.2 Objectives of a Public Participation Program

The objectives of a public participation program are:

1. Promoting full public understanding of the need for a sludge landfill and the principles of its operation

2. Keeping the public well-informed on the status of various planning, design, and operation activities

3. Soliciting from concerned citizens their relevant opinions and perceptions involving sludge landfill development

The key to achieving these objectives is the maintenance of continuous two-way communication between sludge landfill planners/designers/operators and the public. A common problem for engineers and public officials is the assumption that educational, informational, and other one-way communication techniques provide for an adequate dialogue. When designing a public participation program, sufficient mechanisms must be provided for meaningful public input into the decision process (see Section 2.5, Design of a PPP). It must be emphasized that a PPP will increase the lead time required to select, design, and construct a landfill. This fact must be considered when initially determining the need for a new site.

2.3 Advantages and Disadvantages of a PPP

The utility of a public participation program is not universally recognized. Admittedly, there are disadvantages as well as advantages associated with public participation in sludge landfill decision-making. The advantages of a PPP include [1]:

1. An increased likelihood of public approval for the final plans
2. A method of providing useful information to decision-makers, especially where values or factors that are not easily quantified are concerned
3. Assurance that all issues are fully and carefully considered
4. A safety valve in providing a forum whereby suppressed feelings can be aired
5. Increased accountability by decision-makers
6. An effective mechanism to force decision-makers to be responsive to issues beyond those of the immediate project

The disadvantages of a PPP include [1]:

1. A potential for confusion of the issues since many new perspectives may be introduced
2. A possibility that erroneous information will be disseminated from unknowledgeable participants
3. An added cost to the project due to public involvement
4. Possible delays in the project due to public involvement
5. A possibility that the effort will not involve the appropriate people or that citizens will not develop an interest in the project until it is too late for changes to be initiated
6. Public resistance to sludge landfilling may still be high despite the best efforts of a PPP

Despite these disadvantages, a PPP is well worth the extra cost as more expensive project delays are probable if an irate populace becomes involved late in the process. The benefits derived from a PPP will, in the long-run, contribute to an effective decision-making process and outweigh the disadvantages.

2.4 PPP Participants

When designing a PPP, it is imperative to organize an effective publicity campaign that will reach the appropriate people at the proper times throughout the planning process. Special efforts should be made to involve groups and individuals who, from past experience, have demonstrated an interest in environmental affairs or those who are likely to be directly affected by the proposed sludge landfill development. Developing a list of interested persons and organizations for formal and informal notifications and contacts is a good way to ensure public participation. Contacting the following groups and individuals should be part of any PPP [1]:

1. Local elected officials
2. State and local government agencies, including planning commissions, councils of government, and individual agencies
3. State and local public works personnel
4. Conservation/environmental groups
5. Business and industrial groups, including Chambers of Commerce and selected trade and industrial associations
6. Property owners and users of proposed sites and neighboring areas
7. Service clubs and civic organizations, including the League of Women Voters, etc.
8. Media, including newspapers, radio, television, etc.

Depending upon the particular circumstances in each area, the following groups can also be contacted, where appropriate:

1. State elected officials
2. Federal agencies
3. Farm organizations
4. Educational institutions, including universities, high schools, and vocational schools
5. Professional groups and organizations
6. Other groups and organizations, possibly including various urban groups, economic opportunity groups, political clubs and associations, etc.

7. Labor unions

8. Key individuals who do not express their preferences through, or participate in, any groups or organizations

Identifying and contacting these groups is only a first step. A special effort must be made to ensure that the particularly important people, (such as influential individuals, people who are most likely to have strong feelings about the site, and the media) are not only informed, but convinced of the validity of the sludge landfill project. It is crucial that as many of these key groups as possible support the sludge landfill and speak out in favor of it during the public participation program.

It is important that local officials are notified about the project before the issue enters the field of public debate. Again, this approach will allow officials to form a more objective opinion about the project and will prepare them for inquiries from the public.

Identifying specific groups and individuals as targets for public involvement efforts helps to focus time and money on the most likely participants, to focus the objectives of the PPP, and to interpret how well the various involvement mechanisms are working.

2.5 Design of a PPP

The PPP should be tailored to each particular situation in terms of cost and scale. A certain minimum effort should be put into every participation program, but within a basic framework, appropriateness and flexibility are the keys. For example, it makes little sense to expend the same amount of time and dollars for a program involving a sludge landfill site on a totally unused piece of land 25 mi (40 km) from the nearest neighbor as compared with a site in a densely populated urban area. A common sense approach in determining the number and frequency of public involvement mechanisms is recommended.

There are various stages in the sludge landfill development process where public participation is critical. In order to be most effective, a majority of this involvement should come in the beginning of the planning process when public input has the greatest potential for shaping the final plan. It is important to determine the limits to public and political acceptability. By doing so early, the public plays a constructive, as opposed to a reactive, role in decision-making. This section will discuss the critical planning stages where public input is particularly important and the appropriate public participation mechanisms at each stage.

2.5.1 Initial Planning Stage

During the initial planning stage, the scope and scale of the entire PPP should be established. In addition, the organization of PPP components and the use of PPP mechanisms should be determined. This determination should recognize the existence of two general types of PPP mechanisms: (1) interaction techniques which promote two-way communication and (2) educational/informational activities which represent one-way communication from officials to the public. Officials at this point may be operating authorities, elected officials, engineering consultants, or even public relations firms.

Initially, the major activities of this stage are mostly informational/educational. The public should be informed of the purpose of a sludge landfill, the need for one in their community, the general design and operation principles, the projected final land use, potential for creation of new jobs, etc. In addition, the rationale for selecting sludge landfilling over alternative methods such as sludge incineration, landspreading, or composting should be explained to the public at the outset. As initial site investigations get underway, two-way public involvement activities become important. The following mechanisms should be organized during this stage [2]:

1. Public Officials Workshop. The purpose of this meeting is to aquaint the concerned officials with the technical considerations relevant to landfilling and to obtain input from local officials on appropriate timing of activities and areas of potential public concern.
2. Advisory Committee. The role of this group is to help organize citizen support for the proposed plan, to act as a sounding board in providing citizen reactions to various proposals, and to take an active part in decision-making. The group should include representatives of local government departments, community organizations, private industry, and others. Consultant progress reports can be presented during these meetings and later publicized.
3. Mailing list. Comprehensive mailing lists are the foundation of an information output program. They must be representative of a a broad cross-section of groups and individuals and a constant effort is required to expand and update them if they are to be effective.
4. Liaison/contact persons. These positions should be held by persons who are actively involved in the landfill decision-making process; e.g., a consulting engineer, public works official, or other comparably informed individual. In large municipalities it may be advantageous to hire an individual to

handle public relations. These people are indispensable for receiving input, answering questions, expanding mailing lists, and generally being responsive. They ensure that logs are kept of all questions and that issues of general concern are directed to the appropriate people for consideration.

5. Media program. This involves organizing an effective publicity campaign through the use of various media. The media should be contacted as early as possible and every effort should be made to convince them of both the need for a sludge landfill as well as the effectiveness of such landfills before the topic becomes an emotional issue. In this way, objective treatment of the issue by the media is more likely. Again, the extent of this program depends upon the particular situation. Various channels include:

    a. Newspapers. A series of informative articles on sludge landfilling can be timed to appear throughout the project to sustain public interest and serve as an educational tool. Each article or news release can also transmit hard news such as notices of public meetings, or articles describing events at public meetings.

    b. Television. This method can be very expensive, but can also be very useful in transmitting information. However, through careful planning, some free coverage of the project can probably be arranged through news programs, public service announcements, or station editorials.

    c. Advertisements. Full-page newspaper advertisements could be used to relate complex information. They can incorporate a mailback feature to highlight citizen concerns, and solicit participation of interested individuals.

    d. Posters, brochures, or displays. These can be highly effective educational tools, especially when particularly creative and put in high traffic areas or given wide distribution.

    e. Radio advertisements or informational talks. The radio can be used to advertise events or information in much the same way that newspapers are used.

6. Classroom educational materials. This can be an effective way of educating school children and their parents. A more economical approach than presentations in each individual school is to design special newsletters and brochures that can also be distributed to other audiences.

2.5.2 Site Selection Stage

The major activities of the initial planning stage are preparatory mechanisms for the site selection stage. The procedure for site selection generally involves a preliminary screening of numerous potential sites after which several sites are selected for more detailed investigation. These selected sites should be subjected to intense public scrutiny. It is at this point that public participation can play a particularly formative role in determing the final site, design and operation procedures, etc.

The majority of public interest and involvement occurs during the site selection stage. It is important to remember that the most vocal and organized protests also occur during the site selection process. Therefore, the major thrust of the PPP should come during this stage, especially in the form of two-way communication techniques. Major PPP activities to be emphasized during this stage include:

1. Public meetings. These are an excellent mechanism for providing public information, receiving input, and achieving one-to-one contact between consultants, local officials, and the public. They are normally less structured than public hearings and therefore, more likely to result in dialogue. Generally, a series of such meetings are held in different locations within the planning area to provide maximum opportunity for attendance by the public. It is a good arena for the use of audio-visual presentations. These meetings work especially well when there are concrete issues to be discussed, and should be timed to coincide with particularly criticial periods in the decision-making process. For example, the public at these meetings could screen the site selection criteria or even rate the candidate sites against those selected criteria. The more successful meetings are usually a result of heavy advance work. Overcoming public apathy can be difficult, but is critically important in these early planning stages. Consultant contracts should clearly specify the number of public meetings to be held because it is often costly and time-consuming to prepare for them.

2. Workshops. Generally, these have positive results although they are not widely used because of low turnout. Such groups usually involve citizens being given courses of instruction by agency staff, and then addressing specific work efforts on the basis of such instruction. Basically workshops are an educational tool with interaction features.

3. Radio talk-shows. Many communities have local radio talk shows where residents can call in and voice their opinions. The consultant and/or a local official could give a short presentation on the landfill plan and then field callers' questions. This is a good opportunity to dispel some misinformation but views of the callers are not necessarily representative of those of the general public.

2.5.3 Selected Site and Design Stage

In this stage, the landfill site is selected and detailed site design begins. Generally, the number of participants involved may drop off in this stage, but the level of activity may substantially increase. No matter how active the public has been up to this point, nearby residents of the site are not going to be happy with the siting decision. Participation efforts should shift to focus on this particular group. Giving these people a role in site design will alleviate some hostility and, in the long-run, improve the public's opinion of the proposed operation. Appropriate activities in this stage are:

1. Tours/field trips. These are useful activities for special interest groups, such as residents near the selected sludge landfill site, and the press. Before the proposed landfill is opened, a tour of an existing operational sludge landfill should be made. This can be far more effective than countless abstract discussions. After the proposed landfill is opened, tours can be offered of this site to educational and other groups. Arranging for aerial views of proposed and existing sites for small groups by chartering a plane can be especially effective.

2. Audio-visual presentations. These can be quite useful at public information meetings to reach people missed by the field trips. The effectiveness of this tool depends on the quality of the script and visuals, but again, can do a great deal towards dispelling much of the misinformation about sludge landfills based on past experience with improperly run sites.

3. Task forces. The purpose of these groups is to recommend design procedures in areas of particular concern for the public. This group could be a sub-group of the Advisory Committee or a committee made up of residents near the site. The group should have a technical orientation in order to be most effective, but should still represent the various interest groups.

4. Formal public hearings. Although at least one is usually required by law, a public hearing is usually only a formality. They tend to be structured procedures, involving prior notification, placing of materials in depositories for citizen review prior to the hearing, and a formal hearing agenda. The hearing itself usually takes the form of a presentation by the consultants, followed by statements from the citizens in attendance. Questions are normally allowed, but argumentative discussion and "debates" are discouraged because of time limitations. Sponsors tend to prefer to adopt a "listening" posture and allow the public to express itself without challenge. This kind of detached attitude tends to generate a great deal of hostility in the public. It conveys the message that the public is powerless to change engineering decisions and this is precisely the type

of message that a PPP is supposed to dissipate. Since public hearings are usually held in the site selection stage before adoption of the final design plan, they provide an insufficient means of legitimate citizen involvement in the complete planning, design, and operation decision-making process. The responsiveness of a public hearing can be enhanced by having elected officials chairing or at least particiating in the process. Nevertheless, public hearings perform their proper legal and review functions only as part of a total PPP.

2.5.4 Construction and Operation Stage

The role of the public in this stage is limited, but the actions of engineers and sludge landfill operators are extremely important. It is in this stage that the sludge landfill developers must "make good" on their assurances of running a well-operated, well-maintained site. Public confidence in local officials can be reinforced through the proper handling of sludge landfill development. Otherwise, it will be extremely difficult to establish public support for this or any future sludge landfill.

Public involvement at this stage will most likely mainly consist of complaints related to construction and operation activities. Mechanisms to handle this interaction include:

1. Telephone line. This is a good tool to register complaints and concerns and to answer questions. It is important that each call is followed up with a response addressing the actions taken to alleviate the problem.

2. Ombudsman or representative. This is an individual who has the ear of the landfill operators and can mediate difficulties that may arise which the citizens feel are not being handled adequately.

2.6 Timing of Public Participation Activities

Correct timing of the public participation activities is critical. In order to be effective, the program must be diversified and sustained. Table 2-1 lists suggested timing of PPP mechanisms for a sample 15-month landfill project. Public hearings are formalities and, as such, occur at the beginning and end of the planning process. Advisory Committee meetings have the function of providing a forum for progress reports and regular input and, therefore, are scheduled to occur from every 2 to 3 months. Public meetings are held jointly with Advisory Committee meetings and are timed to obtain input during the critical points in decision-making. Sufficient time is allowed after each public meeting to give decision- makers time to react to comments and incorporate suggestions before final determinations are made. The various other informational/educational activities are scheduled around the public and advisory committee meetings in order to arouse public interest at times when input will be the most valuable.

TABLE 2-1

SUGGESTED TIMING OF PUBLIC PARTICIPATION ACTIVITIES
FOR SAMPLE 15-MONTH PROJECT

	Decision stage																
	Initial planning			Site selection							Design			Con-struction		Operation	
	Month																
PPP activities and mechanisms	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Public hearings		ⓧ										ⓧ					
Public meetings		ⓧ				ⓧ			ⓧ			ⓧ			ⓧ		
Advisory Committee meetings		ⓧ		X		ⓧ		X	ⓧ		X	ⓧ			ⓧ		
Mailing list development and mailings	→	→	→	→	→	→	→	→	→	→	→	→	→				
Availability of contact people	→	→	→	→	→	→	→	→	→	→	→	→	→	→	→	→	→
Newspaper articles	X	X	X		X			X									
New releases		X			X			X			X			X			
Audio-visual presentations		X				X			X			X			X		
Newspaper advertisements			X				X			X			X				
Posters, brochures, and displays	→	→	→	→	→	→	→	→	→	→	→	→	→	→	→	→	→
Workshops			X					X									
Radio talk-shows							X			X							
Tours/field trips								X			X				X		X
Ombudsman	→	→	→	→	→	→	→	→	→	→	→	→	→	→	→	→	→
Task force											→	→	→	→			
Telephone line	→	→	→	→	→	→	→	→	→	→	→	→	→	→	→	→	→

ⓧ = joint meeting
ⓧ

As stated before, a great deal of time and effort is involved in a PPP. When budget or time restrictions prohibit development of an ideal program, it is more important to apply participation techniques that are highly effective. Table 2-2 indicates the relative capabilities of the suggested PPP activities.

2.7 Potential Areas of Public Concern

A PPP should serve to dispel any myths and misinformation the public may have concerning sludge landfills. It should also address the irreversible impacts of all landfill developments and other issues of concern in the environmental impact report (see Chapter 4). The most effective participation activities for handling these issues are the interaction techniques (i.e., public meetings, tours/field trips, and displays that are manned by personnel to answer questions). Some of the concerns most likely to arise during sludge landfill development are listed in Table 2-3 along with the chapters that address these issues in the manual.

TABLE 2-2

CAPABILITIES OF PUBLIC PARTICIPATION TECHNIQUES

	Communication characteristics		
Public participation technique	Level of public contact achieved	Ability to handle specific interest	Degree of two-way communication
Public hearings	M	L	L
Public meetings	M	L	M
Advisory Committee meetings	L	H	H
Mailings	M	M	L
Contact persons	L	H	H
Newspaper articles	H	L	L
News releases	H	L	L
Audio-visual presentations	M	L	L
Newspaper advertisements	H	L	L
Posters, brochures, displays	H	L	M
Workshops	L	H	H
Radio talk shows	H	M	H
Tours/field trips	L	H	H
Ombudsman	L	H	H
Task force	L	H	H
Telephone line	H	M	M

L = low
M = medium
H = high

TABLE 2-3

PUBLIC CONCERNS

Public concern	Manual chapter
Pre-development land uses and subsequent environmental impacts	4 - Site Selection
Zoning problems/conflicting land uses	4 - Site Selection
Groundwater pollution and leachate	5 - Design
Gas migration	5 - Design
Vectors	6 - Operation
Noise	6 - Operation
Odor	6 - Operation
Aesthetics - including site visibility	6 - Operation
Safety and health	6 - Operation
Traffic	6 - Operation
Spillage	6 - Operation
Sedimentation and erosion	6 - Operation
Final land use	8 - Completed Site

Local officials should be prepared to handle questions concerning these issues. Obviously a majority of these problems simply do not arise with a well-operated, efficiently-run site, and this fact should be heavily emphasized. Also, since each situation is unique, mechanisms to ease these concerns have to be tailored to the characteristics of each site. Local residents and officials should be creative in solving any problems that may arise. Above all, the attitude of local officials during interactions with citizens is extremely important and must at all times be open and responsive.

2.8 Conclusion

Even the best program to involve the public in sludge landfill decision-making may not alleviate citizen dissatisfaction or anger. This criticism has often been cited to justify only minimal public participation efforts. However, active public involvement will positively contribute to the long-term political and public acceptability of any plan, increase public confidence in local officials, and give citizens a ready opportunity to take part in the land management decisions of their community. A PPP is a necessary part of any sludge landfill program.

2.9 References

1. Canter, L. Environmental Impact Assessment. McGraw- Hill Book Co., New York, New York. 1977. pp. 221, 222.

2. CH_2M Hill, Donahue and Associates, et al. Preliminary Draft: Community Involvement Program, Metropolitan Sewerage District of the County of Milwaukee, Water Pollution Abatement Program. December 1977. pp. A-1-A-8.

CHAPTER 3

SLUDGE CHARACTERISTICS AND LANDFILLING METHODS

3.1 Purpose and Scope

The purpose of this chapter is to present pertinent background information on municipal wastewater treatment sludge and to define alternative sludge landfilling methods. Subsequently, each landfilling method is described in terms of the sludge and site conditions peculiar to that method. For a given combination of sludge and site conditions, a single landfilling method can be selected. Thus, the landfilling method selection (and ultimately the design) requires an accurate inventory of the sludge characteristics. Sections 3.2, 3.3, and 3.4 in this chapter discuss sludge sources, sludge treatment, and sludge characteristics, respectively. Section 3.5 defines the suitability of sludge for landfilling and Section 3.6 discusses alternative sludge landfilling methods and relates them to suitable sludge characteristics and site conditions.

It should be noted that the background discussion on sludge in this chapter has been kept brief. For further information it may be advisable to consult more detailed references on the subject. Excellent references include "Sludge Processing, Transportation, and Disposal/Resource Recovery: A Planning Perspective" [1], "Process Design Manual for Sludge Treatment and Disposal" [2], and "Seminar Handout for Sludge Treatment and Disposal" [3].

3.2 Sludge Sources

In the process of treating wastewater, solids are produced. Various treatment processes are designed to remove specific types of solids.

3.2.1 Primary Treatment

Solids removed in primary treatment may include:

1. Screenings
2. Grit
3. Skimmings
4. Sludge

3.2.1.1 Screenings

Screenings are solids such as rags, sticks, and trash in the raw wastewater that are removed on racks or bar screens placed at the head of the treatment plant. The quantity of screenings captured in a wastewater treatment plant will vary depending upon the size of the rack or screen openings. Screenings may be disposed of separately or ground by hammermills or shredders and added to the wastewater for later removal in sedimentation basins. Screenings typically have a moisture content of 85 to 95% and an organic content of 50 to 80% [1].

3.2.1.2 Grit

Heavy inert material or grit such as sand, silt, gravel, ashes, and coffee grounds are selectively removed at the head of the wastewater treatment plant, either by velocity control in simple gravity settling chambers or by buoyant induction in air flotation tanks. Grit is often washed after collection to reduce the concentration of organics which may be as high as 50% of the total grit solids. The high organics are largely responsible for the odors associated with grit.

3.2.1.3 Skimmings

Skimmings consist of floatable materials collected from sedimentation basins. Skimmings may be subsequently digested, dewatered, incinerated, and/or landfilled. When skimmings are unstabilized, cover may have to be applied immediately at landfills to control odor. Treatment of skimmings in digesters is common, however, particularly with mixed units. Vacuum filtration dewatering normally requires prior mixing with more readily dewaterable materials or the use of a sludge precoat on the filter.

3.2.1.4 Sludge

Sludge which accumulates in the primary clarifier varies from 2 to 8% solids depending on the operating efficiency of the clarifier and on whether thickening is used. The solids mass will increase if there is a substantial amount of ground garbage. Primary sludge has a larger particle size than that for secondary sludges. Anaerobic digestion and the various dewatering techniques are more easily applied to the sludge from primary clarifiers. Nevertheless, primary sludge is frequently mixed with secondary sludge prior to treatment.

3.2.2 Secondary Treatment

The solids from trickling filters thicken in the final clarifier to 1 to 3% by weight, the denser solids resulting from low-loaded filters. The quantity and physical characteristics of the solids from rotating biological contactors are comparable to those from trickling filters.

Activated sludge processes use a suspension of aerobic microorganisms to remove soluble and colloidal organic matter. These organisms can vary in type, concentration, and degree of agglomeration depending upon the physical features of the plant, types of pollutants, and degree of pollutant level. Sludges from these processes range from about 0.5% up to 5% solids depending on the operating efficiency of the clarifier and on whether the waste activated sludge is thickened.

Chemical addition to primary and secondary treatment processes increases sludge mass (and usually volume) with the additional settled colloidal matter and suspended solids from the wastewater and the settled chemicals themselves. In some instances, however, sludge volumes may actually decrease as a result of increased sludge density. Aluminum and iron salts, lime, and organic polymers are frequently employed to enhance the removal of colloidal material, suspended solids, and phosphorus in primary, secondary, and tertiary processes.

3.2.3 Industrial Sources

In extreme cases, industrial influent to municipal wastewater treatment plants can have three harmful effects. They may (1) "upset" biological treatment processes, (2) make sludge treatment and disposal difficult, or (3) create a "pass-through" effect allowing contaminants to reach drinking water sources. Usually, the effects are somewhat less severe and may be limited to (1) increases in heavy metal, refractory organic, or salt concentrations, (2) the addition of slime, or (3) higher concentrations of granular or fibrous material. Viral and bacterial contamination from human waste does not change significantly with increases in industrial waste fractions. Pretreatment regulations [4] now being promulgated by EPA should reduce or cease the harmful effects which industrial influents can have on municipal plants.

3.3 Sludge Treatment

The basic sludge treatment processes and their function are outlined below [2]. Thereafter, brief descriptions of the basic processes are presented.

Unit Processes	Functions
Thickening	Water removal Volume reduction Post process efficiencies Blending
Stabilization	Pathogen destruction Volume and weight reduction Odor control Putrescibility control Gas production Conversion
Conditioning	Improved dewatering or thickening rate Improved solids capture Improved compactability Stabilization
Dewatering	Water removal Volume and weight reduction Improve ease of handling by conversion of liquid sludge to damp cake Reduced fuel requirements for incineration/drying
Heat Drying and Conversion	Destruction of solids/pathogens Conversion Recovery of dried sludge for use as soil conditioner Stabilization

3.3.1 Thickening

In sludge thickening processes, water is extracted from the sludge, thus increasing the sludge solids content and decreasing the sludge volume. The most common methods for thickening are by gravity, air flotation, and centrifugation. If the sludge is to be disposed via sludge-only landfilling, subsequent dewatering will be required. Sludge thickening may provide a blending function in combining and mixing primary and secondary sludges. Sludge thickeners are also used as flow equalization tanks to minimize the effect of sludge quantity fluctuations on subsequent treatment processes.

3.3.2 Stabilization

3.3.2.1 Anaerobic Digestion

Anaerobic digestion is the decomposition of organic matter in the absence of free oxygen. This decomposition is accompanied by gasification and liquifaction which in turn lead to stabilization, colloidal structure breakdown, and release of moisture [5]. Depending upon the initial volatile solids content of the sludge to be treated, anaerobic digestion can achieve a 50 to 70% reduction in volatile solids. The primary purposes of anaerobic digestion [5] are to:

1. Prevent nuisances by decomposing organic solids to a more stable form.
2. Reduce sludge mass by converting organic solids to gases and liquids.
3. Reduce pathogenic organisms.

Other possible uses that anaerogic digesters have performed are:

1. Reduction of volume by concentrating the remaining solids into a denser sludge.
2. Storage of sludge to accommodate fluctuations in wastewater flows and to permit flexibility in subsequent dewatering operations.
3. Homogenization of sludge solids to facilitate subsequent handling procedures.

3.3.2.2 Aerobic Digestion

Aerobic digestion, which takes place in the presence of free oxygen produces a final material consisting of inorganics and volatile solids that resist further biological degradation [1].

3.3.3 Conditioning

Sludge conditioning improves the dewaterability of the sludge by changing its chemical and physical characteristics.

3.3.3.1 Sludge Conditioners

The use of additives for sludge conditioning is widely applied to increase the productivity of mechanical dewatering equipment and obtain greater flexibility in subsequent sludge treatment and disposal processes. Conditioning additives such as ferric chloride, lime, alum, chlorine, organic polymers, and ash are used for coagulation of the sludge solids and release of bound water [1]. Generally, polymer treated sludges tend to be sticky, slick, and less workable than other sludges and frequently require special operational considerations at the landfill. Moreover, some conditioned sludges are corrosive.

3.3.3.2 Elutriation

Elutriation, which involves mixing of digested sludge with water and resettling, improves the dewatering characteristics of the sludge. It also reduces the chemical conditioning requirements by reducing the alkalinity of the sludge, thereby reducing the amount of ferric chloride and lime required if inorganic conditioning is elected. Elutriation should, however, be used in conjunction with polyelectrolytes to settle the fine solids and reduce recirculation.

3.3.3.3 Heat Treatment

Heat treatment is a conditioning process that involves heating the sludge for short periods of time under pressure. Heat treatment results in coagulation of the sludge solids, breakdown of the gel structure of the sludge, and reduction of the water affinity of the sludge solids. Thus, the sludge is sterilized, and generally readily dewatered without the addition of conditioning chemicals [1]. However, heat treatment will solubilize organics and produce a liquid sidestream which may sometimes cause problems. Further, although the sludge produced by heat treatment is practically deodorized, the process itself can be quite malodorous.

3.3.4 Dewatering

There are several methods available for dewatering sludges at present. They include vacuum filters, centrifuges, filter presses, belt presses, lagoons, and sand drying beds. Sludge dewatering processes achieve a degree of water removal immediately between those of thickening and drying. Dewatered sludge solids of 15 to 40% are common with organic sludges, and values of 45% or more can be achieved with some inorganic sludges [6][7].

3.3.4.1 Vacuum Filtration

Vacuum filtration is the most commonly used mechanical dewatering method in the United States. With chemical conditioning, the solids capture can produce a filter cake that ranges from 15 to 25%.

3.3.4.2 Centrifugation

Centrifugation is used in both thickening and dewatering operations and usually in conjunction with chemical conditioning. Centrifugation can produce dewatered cakes generally comparable to those obtained by vacuum filtration [6]. Centrifugation has several advantages over vacuum filtration; it is simple, compact, and totally enclosed (thereby reducing odor problems in the solids handling facilities) [5]. Typically, centrifugation cake solids contents range from 10 to 30%, with values of 40% or more possible [7]. When centrifugation is not done in conjunction with chemical conditioning, solids capture can be a problem.

3.3.4.3 Pressure Filtration

Sludge dewatering by means of a filter press is a batch operation. Sludge is pumped into the press and passes through feed holes along the length of the filter. As the press is closed by either electrical or hydraulic means, water is pressed out of the feed sludge and is discharged through filtrate drain holes. Solids of 30 to 50% are reported in the literature; however this figure may be misleading since solids may be substantially increased through the addition of conditioner solids [3][7].

3.3.4.4 Belt Presses

Belt presses, a relatively recent innovation, produce a broad range of solids, depending on the design of the press and the nature of the feed. Solids ranging from 15 to 40% may be achieved with this process [3].

3.3.4.5 Lagoons and Drying Beds

Lagoons and sand drying beds can be used to both store and dewater sludge, although some stabilization usually occurs. With suitable lagoon depths, retention times, and climates, sludge can be thickened to over 10% solids. Sludge solids up to 40% have been reported in the literature for long detention times [1].

3.3.5 Drying and Conversion

Sludge conversion processes are generally thermal techniques and are intended to reduce the solids required for final disposal or to recover a resource. Table 3-1 indicates the sludge conversion and resource recovery processes. Obviously, the prevailing air pollution regulations and fuel costs should be taken into account. Thus, high costs for auxilliary fuels and air pollution controls may be incurred.

TABLE3-1

CONVERSION PROCESSES [2]

Conversion Process	Pretreatment Required	Additional Processing Requirements
Established Processes		
Incineration	Thickening and dewatering	Landfill ash
Wet air oxidation	Thickening	Treat cooking liquor, landfill ash
Heat drying	Thickening and dewatering	Use dried sludge as soil conditioner
Experimental Processes		
Pyrolysis	Thickening and dewatering	Utilize by-products of gas, carbon, steam. Dispose of residue
Incineration/ chemical recovery	Thickening and dewatering	Landfill ash. Recover lime from recalcination or heat in power boilers

3.3.5.1 Incineration

Combustion by incineration serves as a means of reducing total sludge volume. End products of combustion are usually water, carbon dioxide, sulfur dioxide, and inert ash [6]. The characteristics of ash vary according to the sludge incinerated. Table 3-2 summarizes the content of ash from four treatment plants. A significant portion of the ash can be used as a sludge conditioner. The remaining ash may be landfilled, but it should be noted that the heavy metal content is, of course, higher than sludges and consequently a lower loading rate is advisable.

TABLE 3-2

COMPOSITION OF VARIOUS ASHES (%) [8]

Element	Millcreek	Beckjord	Tahoe	Kansas City
Zinc	0.56	0.10	0.11	0.13
Cadmium	0.07	0.10	0.10	0.10
Arsenic	0.33	0.50	0.50	0.50
Boron	0.26	0.05	0.05	0.18
Phosphorus	0.33	0.50	2.70	0.50
Iron	3.33	5.30	0.97	2.65
Molybdenum	0.13	0.20	0.20	0.20
Manganese	0.03	0.05	0.05	0.05
Aluminum	6.99	9.40	0.29	4.6
Beryllium	0.001	0.001	0.001	0.001
Copper	0.03	0.07	0.05	0.05
Silver	0.01	0.01	0.01	0.01
Nickel	0.07	0.10	0.10	0.10
Cobalt	0.07	0.10	0.10	0.10
Lead	0.13	0.20	0.20	0.20
Chromium	0.23	0.05	0.14	0.10
Vanadium	0.13	0.20	0.20	0.20
Barium	0.26	0.01	0.03	0.08
Strontium	0.01	0.01	0.01	0.01
Calcium	8.46	1.5	21.13	6.18
Silicon	22.00	19.17	11.15	26.96
Magnesium	1.00	0.45	1.30	0.51
Other	55.57	61.93	60.61	56.59

3.3.5.2 Wet Air Oxidation

Wet air oxidation involves burning of organic matter in the absence of flame and in the presence of liquid water. Temperatures and pressures on the order of 400 to 600°F (150 to 225°C) and 1200 to 1800 psig (8.3×10^2 to 1.2×10^3 N/cm^2) are used for complete oxidation of organics [6]. Because it is not necessary to supply energy for the latent heat of vaporization of water, wet air oxidation is particularly applicable for materials like organic sludges which are combustible but cannot be readily separated from water. A problem with ash disposal in the wet air oxidation process is that the ash is conveyed in a significant volume of water.

3.3.5.3 Heat Drying

Heat (flash) drying is the instantaneous removal of moisture from sludge solids by introducing them into a hot gas stream. Wet sludge from a dewatering process is mixed with previously dried sludge, pulverized, and introduced into the dryer. Drying by the hot gases from the furnace is essentially complete, with the sludge having solids contents in excess of 90%. Initially, dried sludge is separated from the spent gases in a cyclone. Subsequently, it may be (1) mixed with wet sludge from the dewatering process, (2) stored for use as soil conditioner, (3) incinerated, or (4) handled in other ways.

3.3.5.4 Pyrolysis

Pyrolysis is defined as the gasification and/or liquefaction of the combustible elements in sludge by heat in the total absence of oxygen. Most of the combustion process is carried out within a closed reactor chamber, normally at temperatures lower than in incinerators. End products of the process are gases, pyroligneous acids and tars, and char. Generally, part of the solids may be used as a fuel and part can be used as a filter aid. The remaining solids must be disposed. Most so-called pyrolysis systems on-line today are actually partial pyrolysis or starved air combustion. Partial pyrolysis uses less than the stoichiometric air requirements but does allow some oxygen to enter the system.

3.3.5.5 Lime Recalcination

The process of recalcining involves incinerating the dewatered sludge containing calcium which drives off water, organics, and carbon dioxide and leaves calcium oxide (quicklime). After coagulating raw wastewaters, the inert solid fraction can be removed before recalcination using a wet centrifugation classification system. This inert solid removal must occur to prevent solids buildup within the wastewater treatment process.

3.4 Sludge Characteristics

The following characteristics of sludge are discussed in this section:

1. Solids content
2. Solids characteristics
3. Pathogens
4. Heavy metals
5. Nitrogen

3.4.1 Solids Content

The solids content of sludge is dependent on its respective treatment source (i.e., primary, secondary, etc.) and on the various sludge treatment processes (stabilization, dewatering, etc.). The efficiency of various dewatering processes for increasing the solids content is critical. For example, if a vacuum filtration unit designed to produce sludge with 25% solids, instead produced sludge with a solids content ranging from 15 to 20%, severe operational problems could occur at the landfill. Only by incorporating flexibility into the design of the landfill can a site handle the variations in sludge that may commonly occur.

3.4.2 Solids Characteristics

The reaction of the macroscopic and microscopic particles in sludge is a function of (1) particle size and distribution, (2) particle configuration, (3) density and (4) other factors such as the microorganisms or free radicals present. Particle size and distribution and configuration of individual particles are dependent upon the sources of sludge. Particles may take on a fibrous, spherical, helical, planar, or cubic configuration. Particle characteristics impact on sludge stability and consistency.

Solids may be further classified as volatile or non-volatile. Volatile solids are a measure of the amount of organic matter present in the solid fraction of sludge. The organic matter may be ultimately broken down by bacteria, producing methane gas via anaerobic digestion or other chemical, physical, or biological processes. Table 3-3 outlines typical values for volatile solids content and other parameters for raw and anaerobically digested primary sludge.

TABLE 3-3

TYPICAL COMPOSITION OF RAW AND ANAEROBICALLY DIGESTED PRIMARY SLUDGES [9]

Item	Raw Primary Sludge		Anaerobically Digested Primary Sludge	
	Range	Typical	Range	Typical
Total dry solids (TS), %	2-7	4	6-20	10
Volatile solids (% of TS)	60-80	65	30-60	40
Grease of fats (ether soluble, % of TS)	6-30	---	5-20	---
Protein (% of TS)	20-30	25	15-20	18
Nitrogen (N, % of TS)	1.5-4	2.5	1.6-6	3
Phosphorus (P_2O_5, % of TS)	0.8-2.8	1.6	1.5-4	2.5
Potash (K_2O, % of TS)	0-1	0.4	0-3	1
Cellulose (% of TS)	8-15	10	8-15	10
Iron (not as sulfide)	2-4	2.5	3-8	4
Silica (SiO_2, % of TS)	15-20	---	10-20	---
pH	5-8	6	6.7-7.5	7
Alkalinity (mg/l as $CaCO_3$)	500-1,500	600	2,000-3,500	3,000
Organic acids (mg/l as HAc)	200-2,000	500	100-600	200
Thermal content (BTU/lb)	6,800-10,000	7,600[a]	2,700-6,800	4,000[b]

Note: --- means data not shown in reference cited.

1 BTU/lb = 0.556 cal/kg

[a] Based on 65% volatile matter

[b] Based on 40% volatile matter

The volume of sludge produced at a treatment facility is dependent upon the influent wastewater characteristics, the efficiency of the processes to reduce pollutants, and the type of sludge treatment process. For example, dewatering processes reduce sludge volumes by removing water, thus reducing the overall weight of the sludge. Table 3-4 outlines the quantities of sludge produced from various treatment processes.

The addition of polymers to sludges will create a more viscous, sticky, slippery material that can cause handling difficulties. If polymers have been added to the sludge, a higher solids content may be required for a specific landfilling method.

3.4.3 Pathogens

Most sludge treatment processes significantly reduce the number of pathogens and decrease the chances for pathogenic contamination. Current research indicates that undigested sludge stabilized with lime to a final pH between 10 and 11 disposed in narrow trenches is not thought to pose a serious hazard [9][10]. Earlier works produced similar results; fecal coliforms and pathogenic salmonella bacteria were not detected more than a few in. (cm) into soils outside of entrenched sludges at any time during a two-year period following entrenchment [11].

3.4.4 Heavy Metals

One of the largest contributors of heavy metals to municipal wastewater treatment plants has been industry. Most heavy metals in wastewater are removed by conventional treatment processes and concentrated in the sludge. Treatment plants should analyze their sludges to determine the concentrations of heavy metals. Typical concentrations of heavy metals and other constituents in raw and digested municipal wastewater sludge are listed in Table 3-5.

The movement of heavy metals through the soil is enhanced by acidic conditions. For this reason, lime (CaO) is added to sludge prior to dewatering to raise pH levels to 10 or 11 [12]. Generally, metals did not leach from entrenched sludge into soils as long as the pH remained near neutral [9][10]. On the other hand, for entrenched, unlimed sludges, the soil and sludge became acidic due to the formation of nitrates and sulfates, and the extent of heavy metal movement increased [11][13].

TABLE 3-4

TYPICAL QUANTITIES OF SLUDGE PRODUCED BY DIFFERENT TREATMENT PROCESSES [1]

Treatment process	Normal quantity of sludge			Moisture %	Specific gravity of sludge solids	Specific gravity of sludge	Dry Solids	
	Gal/ million gal of sewage	Wet tons/ million gal of sewage	Cu ft/ 1,000 persons daily				Dry lb/ million gal of sewage	Dry lb/ 1,000 persons daily
Primary sedimentation:								
Undigested	2,950	12.5	39.0	95	1.40	1.02	1,250	125
Digested in separate tanks	1,450	6.25	19.0	94	--	1.03	750	75
Digested and dewatered on sand beds	--	0.94	5.7	60	--	--	750	75
Digested and dewaterd on vacuum filters	--	1.36	4.3	72	--	1.00	750	75
Trickling filter	745	3.17	9.9	92	1.33	1.025	476	48
Chemical precipitation	5,120	22.0	68.5	92	1.93	1.03	3,300	330
Dewatered on vacuum filters	--	6.0	19.3	72	--	--	3,300	330
Primary sedimentation and activated sludge:								
Undigested	6,900	29.25	92.0	96	--	1.02	2,340	234
Undigested and dewatered on vacuum filters	1,480	5.85	20.0	80	--	0.95	2,340	234
Digested in separate tanks	2,700	11.67	36.0	94	--	1.03	1,400	140
Digested and dewatered on sand beds	--	1.75	18.0	60	--	--	1,400	140
Digested and dewatered on vacuum filters	--	3.5	11.7	80	--	0.95	1,400	140
Activated sludge:								
Wet sludge	19,400	75.0	258.0	98.5	1.25	1.005	2,250	225
Dewatered on vacuum filters	--	5.62	19.0	80	--	0.95	2,250	225
Dried by heat dryers	--	1.17	3.0	4	--	1.25	2,250	225
Septic tanks digested	900		12.0	90	1.40	1.04	810	81
Imhoff tanks, digested	500		6.7	85	1.27	1.04	690	69

---

[a] Based on a sewage flow of 100 gal/capita/d and 300 ppm, or 0.25 lb per capita daily, or suspended solids in sewage.

1 ft^3 = 28.32 l
1 gal = 3.785 l
1 ton = 907.2 kg
1 lb = 0.454 kg

TABLE 3-5

CHEMICAL COMPOSITION OF MUNICIPAL WASTEWATER SLUDGES[a] [14]

Component	Units	Number of samples	Range	Median	Mean	Coefficient of variability, %[c]
Total N	%[b]	191	0.1-17.6	3.3	3.9	85
NH_4-N		103	0.1- 6.8	0.1	0.7	171
NO_3-N		45	0.1- 0.5	0.1	0.1	158
P		189	0.1-14.3	2.3	2.5	61
K		192	0.1- 2.6	0.3	0.4	99
Ca		193	0.1-25.0	3.9	4.9	87
Mg		189	0.1- 2.0	0.5	0.5	75
Fe		165	0.1-15.3	1.1	1.3	148
Mn	mg/kg[b]	143	18-7,100	260	380	209
B		109	4-760	33	77	162
Hg		78	0.5-10,600	5	733	232
Cu		205	84-10,400	850	1,210	138
Zn		208	101-27,800	1,740	2,790	134
Ni		165	2- 3,520	82	320	162
Pb		189	13-19,700	500	1,360	177
Cd		189	3- 3,410	16	110	157

---

[a] Data are from numerous types of sludges (anaerobic, aerobic, activated, lagoon, etc.) in seven states: Wisconsin, Michigan, New Hampshire, New Jersey, Illinois, Minnesota, Ohio

[b] Percent or mg/kg oven-dry solids basis.

[c] Standard deviation as a percentage of mean. Number of samples on which this is based may not be the same as for other columns.

3.4.5 Nitrogen

The nitrogen species in sludge represents a source of groundwater pollution [11]. Due to the many mechanisms associated with nitrogen movement, it is difficult to predict the risk of pollution. The potential for groundwater pollution is significantly affected by the total quantity of nitrogen present and the species, which include nitrogen, ammonia, nitrate, and nitrite. Generally, nitrate is the principal species of concern and is relatively mobile in most soil types. Aerobic conditions facilitate microbial conversion of other nitrogen species to nitrate, and thus, increase the possibility for nitrogen movement. Therefore, disposal methods providing anaerobic conditions inhibit nitrogen movement and allow microbial destruction of pathogens [11].

3.5 Suitability of Sludge for Landfilling

In determining the suitability of sludge for landfilling, a determination should be made of the sludge sources and treatment. Analyses should also be performed on the sludge to determine relevant characteristics. This information is needed in order that a full assessment can be made of its suitability for landfilling. Not all wastewater treatment sludges are suitable for landfilling due to either odor or operational problems. An assessment of the suitability of various sludge types has been included as Table 3-6.

As shown, only dewatered sludges (having solids contents greater than or equal to 15%) are suitable for disposal in sludge-only landfills. Sludges having solids contents less than 15% usually will not support cover material. Obviously, the addition of soil to a low-solids sludge may act as a bulking agent and produce a sludge suitable for disposal at sludge-only landfills. However, soil bulking operations are generally not cost-effective on sludges with solids less than 15%. Further dewatering should be performed at the treatment plant if sludge-only landfilling is the disposal option selected. Low-solids sludge (having solids contents as low as 3%) are suitable for codisposal landfilling. However, sludge moisture should not exceed the absorptive capacity of refuse at a codisposal landfill. Accordingly, low-solids sludge should be received at such sites only if it constitutes a small percentage of the total waste landfilled.

Generally, only stabilized sludges are recommended for landfilling and some degree of stabilization should occur if landfilling is the selected disposal option. However, since stabilization is not required in all states, suggested procedures for landfilling such sludges are described.

The following section describes handling and operating practices for typical sludges. Sludge ash as well as other wastewater treatment plant solids such as screenings, grit, and skimmings are disposed essentially in the same manner. Specific handling of these wastes is described in Chapter 6, Operation.

3.6 Sludge Landfilling Methods

The purpose of this section is to identify and describe several alternative methods and sub-methods for sludge landfilling. These include:

1. Sludge-only trench
    a. Narrow trench
    b. Wide trench
2. Sludge-only area fill
    a. Area fill mound
    b. Area fill layer
    c. Diked containment

TABLE 3-6

SUITABILITY OF SLUDGES FOR LANDFILLING

		Sludge-only landfilling		Codisposal landfilling	
Process	Feed	Suitability	Reason	Suitability	Reason
Thickening					
Gravity	Primary	NS	OD, OP	NS	OD, OP
	WAS	NS	OD, OP	NS	OD, OP
	Primary and WAS	NS	OD, OP	NS	OD, OP
	Digested primary	NS	OP	MS	OP
	Digested primary and WAS	NS	OP	MS	OP
Flotation	Primary and WAS	NS	OD, OP	NS	OD, OP
	WAS with chemicals	NS	OP	NS	OD, OP
	WAS without chemicals	NS	OD, OP	NS	OD, OP
Treatment					
Aerobic digestion	Primary, thickened	NS	OP	MS	OP
	Primary and WAS, thickened	NS	OP	MS	OP
Anaerobic digestion	Primary, thickened	NS	OP	MS	OP
	Primary and WAS thickened	NS	OP	MS	OP
Incineration	Primary, dewatered	S	--	S	--
	Primary and WAS, dewatered	S	--	S	--
Wet oxidation	Primary or primary and WAS	NS	OD,OP	MS	OD,OP
Heat	Any, thickened	NS	OD,OP	MS	OD,OP
Lime stabilization	Primary, thickened	NS	OP	MS	OP
	Primary and WAS, thickened	NS	OP	MS	OP
Dewatering					
Drying beds	Any, digested	S	--	S	--
	Any, lime stabilization	S	--	S	--
Vacuum filter	Primary, lime conditioned	S	--	S	--
	Digested, lime conditioned	S	--	S	--
Pressure filtration	Digested, lime conditioned	S	--	S	--
Centrifugation	Digested	S	--	S	--
	Digested, lime conditioned	S	--	S	--
Heat drying	Digested	S	--	S	--

WAS = Waste Activated Sludge
NS = Not Suitable
MS = Marginally Suitable
S = Suitable
OD = Odor Problems
OP = Operational Problems

3. Codisposal

   a. Sludge/refuse mixture
   b. Sludge/soil mixture

The above-listed alternatives were found to be an appropriate classification of major sludge landfilling methods. Other methods were considered and some do exist in practice. However, these other methods either (1) did not afford sufficient protection of the environment, (2) were not practical, or (3) were similar in many aspects to the methods listed above.

In this section, each method is defined and subsequently described in terms of sludge and site conditions specific to that method. In addition, design criteria are identified for each method. The criteria suggested for each method are based on experiences at numerous sludge landfills which embrace a broad range of sludge and site conditions. These criteria should be valid for the majority of sludge landfill applications. However, design criteria should be qualified as being "typical" or "recommended". Variations are employed and may be appropriate in some cases. For example, the range of sludge solids contents recommended for each method in this section may vary somewhat depending on the sludge source, treatment, and characteristics. Specifically, a sludge treated with polymers is more slippery and less stable; consequently it will require a higher solids content to be landfilled in the same manner as a sludge not treated with polymers. Nevertheless, the criteria suggested by this section can serve as a starting point. It is recommended that field tests be performed to ensure that an operation based on the criteria in this section will function properly for a given sludge and site.

3.6.1 Sludge-Only Trench

For sludge-only trenches, subsurface excavation is required so that sludge can be placed entirely below the original ground surface. Trench applications require that groundwater and bedrock be sufficiently deep so as to allow excavation and still maintain sufficient buffer soils between the bottom of sludge deposits and the top of groundwater or bedrock.

In trench applications, soil is used only for cover and is not used as a sludge bulking agent. The sludge is usually dumped directly into the trench from haul vehicles. On-site equipment is normally used only for trench excavation and cover application; it is not normally used to haul, push, layer, mound, or otherwise come into contact with the sludge.

Although in some cases cover application may be less frequent, cover is normally applied over sludge the same day that it is received. Because of the frequency of cover, odor control is optimized; therefore, trenches are more appropriate for unstabilized or low-stabilized sludges than other landfilling methods. The soil excavated during trench construction provides quantities which are almost always sufficient for cover applications. Accordingly, soil importation is seldom required in trench applications.

Two sub-methods have been identified under trench applications. These include (1) narrow trench and (2) wide trench. Narrow trenches are defined as having widths less than 10 ft (3.0 m); wide trenches are defined as having widths greater than 10 ft (3.0 m). The depth and length of both narrow and wide trenches are variable and dependent upon a number of factors. Trench depth is a function of (1) depth to groundwater and bedrock, (2) sidewall stability, and (3) equipment limitations. Trench length is virtually unlimited, but inevitably dependent upon property boundaries and other site conditions. In addition, trench length may be limited by the need to discontinue the trench for a short distance or place a dike within the trench to contain a low-solids sludge and prevent it from flowing throughout the trench.

3.6.1.1 Narrow Trench

As stated previously, a narrow trench has a width of less than 10 ft (3.0 m). Sludge is usually disposed in a single application and a single layer of cover soil is applied atop this sludge. Narrow trenches are usually excavated by equipment based on solid ground adjacent to the trench and equipment does not enter the excavation. Accordingly, backhoes, excavators, and trenching machines are particularly useful in narrow trench operations. Excavated material is usually immediately applied as cover over an adjacent sludge-filled trench. However, occasionally, it is stockpiled alongside the trench from which it was excavated for subsequent application as cover over that trench. Cover material is then applied by equipment also based on solid ground outside of the trench. Relevant sludge and site conditions as well as design criteria are presented in the following tabulation.

Sludge and Site Conditions

Sludge solids content	- 15-20% for 2-3 ft (0.6-0.9 m) widths - 20-28% for 3-10 ft (0.9-3.0 m) widths
Sludge characteristics	- unstabilized or stabilized
Hydrogeology	- deep groundwater and bedrock
Ground slopes	- <20%

Design Criteria

Trench width - 2-10 ft (0.6-3.0 m)

Bulking required - no

Cover soil required - yes

Cover soil thickness - 3-4 ft (0.9-1.2 m)

Imported soil required - no

Sludge application rate - 1,200-5,600 yd^3/acre (2,300-10,600 m^3/ha)

Equipment - backhoe with loader, excavator, trenching machine

The main advantage of a narrow trench is its ability to handle sludge with a relatively low solids content. As shown above, a 2 to 3 ft (0.6 to 0.9 m) width is required for sludge with a solids content between 15 and 20%. Normally, soil applied as cover over sludge of such low solids would sink to the bottom of the sludge. However, because of the narrowness of the trench, the soil cover bridges over the sludge, receiving support from solid ground on either side of the trench. In this operation cover is usually applied in a 2 to 3 ft (0.6 to 0.9 m) thickness.

A 3 to 10 ft (0.9 to 3.0 m) width is more appropriate for sludge with solids contents from 20 to 28%. At this width, the bridging effect of the cover soil is non-existent. However, the solids content is high enough to support cover. In this operation, cover is usually applied in a 3 to 4 ft (0.9 to 1.2 m) thickness and dropped from a minimum height to minimize the amount of soil that sinks into sludge deposits.

The main disadvantage of narrow trench operations is that it is relatively land-intensive. As shown above, typical sludge application rates in actual fill areas (including inter-trench areas) range from 1,200 to 5,600 yd^3/acre (2,300 to 10,600 m^3/ha). Generally, application rates for narrow trenches are less than for other methods. Another drawback with narrow trench operations is that liners are impractical to install.

3.6.1.2 Wide Trench

As stated previously, a wide trench has a width of greater than 10 ft (3.0 m). Wide trenches are usually excavated by equipment operating inside the trench. Accordingly, track loaders, draglines, scrapers, and track dozers are particularly useful in wide trench operations. Excavated material is usually stockpiled on solid ground adjacent to the trench from which it was excavated for subsequent application as cover over that trench. However, occasionally it is immediately applied as cover over an adjacent sludge-filled trench. Relevant sludge and site conditions as well as design criteria are presented in the following tabulation.

Sludge and Site Conditions

Sludge solids content - 20-28% for land-based equipment
- ≥28% for sludge-based equipment

Sludge characteristics - unstabilized or stabilized

Hydrogeology - deep groundwater and bedrock

Ground slopes - <10%

Design Criteria

Trench width - >10 ft (3.0 m)

Bulking required - no

Cover soil required - yes

Cover soil thickness - 3-4 ft (0.9-1.2 m) for land-based equipment
- 4-5 ft (1.2-1.5 m) for sludge-based equipment

Imported soil required - no

Sludge application - 3,200-14,500 yd^3/acre (6,000-27,400 m^3/ha)

Equipment - track loader, dragline, scraper, track dozer

As shown above, cover material may be applied to wide trenches in either of two different ways. If its solids content is from 20 to 28%, the sludge in the trench is incapable of supporting equipment. Therefore, cover should be applied in a 3 to 4 ft (0.9 to 1.2 m) thickness by equipment based on solid undisturbed ground adjacent to the trench. In this way, a wide trench may be only slightly more than 10 ft (3.0 m) wide (if a front-end loader is used to apply cover) or up to 50 ft (15 m) wide (if a dragline is used to apply cover). Alternatively, if its solids content is 28% or more covered sludge in the trench is capable of supporting equipment. Therefore, cover should be applied by equipment which proceeds out over the sludge pushing a 4 to 5 ft (1.2 to 1.5 m) thickness of cover before it. Track dozers are the most useful piece of equipment in this application.

As for narrow trenches, wide trenches should be oriented parallel to one another to minimize inter-trench areas. Distances between trenches should be only large enough so as to provide sidewall stability as well as adequate space for soil stockpiles, operating equipment, and haul vehicles.

One advantage of a wide trench is that it is less land-intensive than narrow trenches. Typical sludge application rates range from 3,200 to 14,500 yd^3/acre (6,000 to 27,400 m^3/ha). Another advantage of a wide trench is that liners can be installed to contain sludge moisture and protect the groundwater. Therefore, excavation may proceed closer to bedrock or groundwater in wide trenches with liners than in narrow trenches without such protection.

One disadvantage of a wide trench is a need for a higher solids sludge, with solids contents at 20% and above. It should be noted that sludges with a solids content of 32% or more will not spread out evenly in a trench when dumped from atop the trench sidewall. If wide trenches are used for such high solids sludge, haul vehicles should enter the trench and dump the sludge directly onto the trench floor. Another disavantage of a wide trench is its need for flatter terrain than that used for narrow trenches. For wide trench applications with sludge less than 32% solids, sludge is dumped from above and spreads out evenly within the trench. Accordingly, the trench floor should be nearly level, and this can be more easily effected when located in low relief areas.

3.6.2 Sludge-Only Area Fill

For sludge-only area fills, sludge is usually placed above the original ground surface. Because excavation is not required and sludge is not placed below the surface, area fill applications are particularly useful in areas with shallow groundwater or bedrock. The solids content of sludge as received is not necessarily limited. However, because the sidewall containment (available in a trench) is lacking and equipment must be supported atop the sludge in most area fills, sludge stability and bearing capacity must be relatively good. To achieve these qualities, soil is usually mixed with the sludge as a bulking agent. Since excavation is not usually performed in the landfilling area, and since shallow groundwater or bedrock may prevail, the large quantities of soil required usually must be imported from off-site or hauled from other locations on-site.

Because filling proceeds above the ground surface, liners can be more readily installed at area fill operations than at trench operations. Of course, because of the likely proximity of groundwater or bedrock to the ground surface, the installation of a liner will often be required at area fills. With or without liners, surface runoff of moisture from the sludge and contaminated rainwater should be expected in greater quantities at area fills, and appropriate surface drainage control facilities should be considered.

In area fills, the landfilling area usually consists of several consecutive lifts or applications of sludge/soil mixture and cover soil. As for any landfill, cover should be applied atop all sludge applications. However, this cover often is applied as necessary to provide stability for additional lifts. Because some time may lapse between consecutive sludge applications, daily cover is usually not provided and stabilized sludges are better suited for area filling than are unstabilized sludges.

Three sub-methods have been identified under area fill applications. These include (1) area fill mound, (2) area fill layer, and (3) diked containment. Each of these three sub-methods are described subsequently.

3.6.2.1 Area Fill Mound

In area fill mound applications, it is recommended that the solids content of sludge received at the site be no lower than 20%. Sludge is mixed with a soil bulking agent to produce a mixture which is more stable and has greater bearing capacity. As shown below, appropriate bulking ratios may vary between 0.5 and 2 parts soil for each part of sludge. The exact ratio employed will depend on the solids content of the sludge as received and the need for mound stability and bearing capacity (as dictated by the number of lifts and equipment weight).

The sludge/soil mixing process is usually performed at one location and the mixture hauled to the filling area. At the filling area, the sludge/soil mixture is stacked into mounds approximately 6 ft (1.8 m) high. Cover material is then applied atop these mounds in a minimum 3 ft (0.9 m) thick application. This cover thickness may be increased to 5 ft (1.5 m) if additional mounds are applied atop the first lift. Relevant sludge and site conditions as well as design criteria are presented in the following tabulation.

Sludge and Site Conditions

Sludge solids content - ≥20%

Sludge characteristics - stabilized

Hydrogeology - shallow groundwater or bedrock possible

Ground slopes - suitable for steep terrain as long as an area is prepared for mounding

Design Criteria

Bulking required - yes

Bulking agent - soil

Bulking ratio - 0.5-2 soil:1 sludge

Cover soil required - yes

Cover soil thickness - 3 ft (0.9 m) of interim
- 1 ft (0.3 m) of final

Imported soil required - yes

Sludge application - 3,000-14,000 yd^3/acre (5,700-34,600 m^3/ha)

Equipment - track loader, backhoe with loader, track dozer

Because equiment may pass atop the sludge in performing mixing, mounding, and covering operations, lightweight equipment with swamp pad tracks is generally recommended for area fill mound operations. However, heavier wheel equipment may be more appropriate in transporting bulking material to and from soil stockpiles.

An advantage of the area fill mound operation is its good land utilization. Sludge application rates are relatively high at 3,000 to 14,000 yd^3/acre (5,700 to 26,400 m^3/ha). A disadvantage is the constant need to push and stack slumping mounds. For this reason, area fill mounds often have higher manpower and equipment requirements. Some slumping is inevitable and occurs particularly in high rainfall areas due to moisture additions to the sludge. Slumping can sometimes be minimized by providing earthen containment of mounds where possible. For example, area fill mound operations are usually conducted on level ground to prevent mounds from flowing downhill. However, if a steeply sloping site is selected, a level mounding area could be prepared into the slope and a sidewall created for containment of mounds on one side.

3.6.2.2 Area Fill Layer

In area fill layer applications, sludge received at the site may be as low as 15% solids. Sludge is mixed with a soil bulking agent to produce a mixture which is more stable and has greater bearing capacity. Typical bulking ratios range from 0.25 to 1 part soil for each part sludge. As for area fill mounds, the ratio will depend on the solids content of the sludge as received and the need for layer stability and bearing capacity (as dictated by the number of layers and the equipment weight).

This mixing process may occur either at a separate sludge dumping and mixing area or in the filling area. After mixing the sludge with soil, the mixture is spread evenly in layers from 0.5 to 3 ft (0.15 to 0.9 m) thick. This layering usually continues for a number of applications. Interim cover between consecutive layers may be applied in 0.5 to 1 ft (0.15 to 0.3 m) thick applications. Final cover should be from 2 to 4 ft (0.6 to 1.2 m) thick. Relevant sludge and site conditions as well as design criteria are presented in the following tabulation.

Sludge and Site Conditions

Sludge solids content	- ≥15%
Sludge characteristics	- stabilized
Hydrogeology	- shallow groundwater or bedrock possible
Ground slopes	- suitable for medium slopes but level ground preferred

Design Criteria

Bulking required	- yes
Bulking agent	- soil
Bulking ratio	- 0.25-1 soil:1 sludge

Cover soil required	- yes
Cover soil thickness	- 0.5-1 ft (0.15-0.3 m) of interim - 2-4 ft (0.6-1.2 m)
Imported soil required	- yes
Sludge application	- 2,000-9,000 yd^3/acre (3,800-17,000 m^3/ha)
Equipment	- track dozer, grader, track loader

As for mounding operations, equipment will also pass atop sludge in performing mixing, layering, and covering functions. Accordingly, lightweight equipment with swamp pad tracks is generally recommended for area fill layer operations. However, heavier wheel equipment may be appropriate for hauling soil. Slopes in layering areas should be relatively flat to prevent the sludge from flowing downhill. However, if the sludge solids content is high and/or sufficient bulking soil is used, this effect can be prevented and layering performed on mildly sloping terrain.

An advantage of an area fill layer operation is that completed fill areas are relatively stable. As a result, the maintenance required is not as extensive as for area fill mounds. Accordingly, manpower and equipment requirements are less. A disadvantage is poor land utilization with application rates from 2,000 to 9,000 yd^3/acre (3,780 to 17,000 m^3/ha).

3.6.2.3 Diked Containment

In diked containment applications, sludge is placed entirely above the original ground surface. Dikes are constructed on level ground around all four sides of a containment area. Alternatively, the containment area may be placed at the toe of a hill so that the steep slope can be utilized as containment on one or two sides. Dikes would then be constructed around the remaining sides.

Access is provided to the top of the dikes so that haul vehicles can dump sludge directly into the containment. Interim cover may be applied at certain points during the filling, and final cover should be applied when filling is discontinued. Relevant sludge and site conditions as well as design criteria are presented in the following tabulation.

Sludge and Site Conditions

Sludge solids content	- 20-28% for land-based equipment - $\geq$28% for sludge-based equipment
Sludge characteristics	- unstabilized or stabilized
Hydrogeology	- shallow groundwater or bedrock possible
Ground slopes	- suitable for steep terrain as long as a level area is prepared inside dikes

Design Criteria

Bulking required	- no, but sometimes used
Bulking agent	- soil
Bulking ratio	- 0.25-1 soil:1 sludge
Cover soil required	- yes
Cover soil thickness	- 1-2 ft (0.3-0.6 m) of interim with land-based equipment - 2-3 ft (0.6-0.9 m) of interim with sludge-based equipment - 3-4 ft (0.9-1.2 m) of final with land-based equipment - 4-5 ft (1.2-1.5 m) of final with sludge-based equipment
Imported soil required	- yes
Sludge application	- 4,800-15,000 yd^3/acre (9,100-28,400 m^3/ha)
Equipment	- dragline, track dozer, scraper

As shown above, the solids content of sludge received at diked containments should be a minimum of 20%. For sludges with solids contents between 20 and 28%, cover material should be applied by equipment based on solid ground atop the dikes. For this situation, a dragline is the best equipment for cover application due to its long reach. Thicknesses should be 1 to 2 ft (0.3 to 0.6 m) for interim cover and 3 to 4 ft (0.9 to 1.2 m) for final cover.

For sludges with solids contents of 28% and above, cover material should be applied by equipment which pushes and spreads cover soil into place as it proceeds out over the sludge. For this situation, a track dozer is the best equipment for cover application. Thicknesses should be 2 to 3 ft (0.6 to 0.9 m) for interim cover and 4 to 5 ft (1.2 to 1.5 m) for final cover.

Usually diked containment operations are conducted without the addition of soil bulking agents. Occasionally, however, soil bulking is added. Under these circumstances, soil may be added to increase the solids content and allow the operations described above.

An advantage of this method is that individual diked containments are relatively large with typical dimensions of 50 to 100 ft (15 to 30 m) wide, 100 to 200 ft (30 to 60 ft) long, and 10 to 30 ft (3 to 9 m) deep. Accordingly, efficient land use is realized with sludge loading rates varying between 4,800 and 15,000 yd^3/acre (9,100 to 28,400 m^3/ha). A disadvantage of diked containment is that the depth of the fill in conjunction with the weight of interim and final cover, places a significant surcharge on the sludge. As a result, much of the sludge moisture is squeezed into surrounding dikes and into the floor of the containment. Accordingly, liners and other leachate controls may be especially appropriate with diked containments to collect leachate emissions.

3.6.3 Codisposal

A codisposal operation is defined as the receipt of sludge at a refuse landfill. Two sub-methods have been identified under codisposal operations. These include (1) sludge/refuse mixture and (2) sludge/soil mixture.

3.6.3.1 Sludge/Refuse Mixture

In a sludge/refuse mixture operation, sludge is deposited at the working face of the landfill and applied atop refuse. The sludge and refuse are then mixed as thoroughly as possible. This mixture is then spread, compacted, and covered in the usual manner at a refuse landfill. Relevant sludge and site conditions as well as design criteria are presented in the following tabulation.

Sludge and Site Conditions

Sludge solids content - ≥3%

Sludge characteristics - unstabilized or stabilized

Hydrogeology - deep or shallow groundwater or bedrock

Ground slopes - <30%

Design Criteria

Bulking required - yes

Bulking agent - refuse

Bulking ratio - 4-7 tons refuse:1 wet ton sludge

Cover soil required - yes

Cover soil thickness
- 0.5-1 ft (0.15-0.3 m) of interim
- 2 ft (0.6 m) of final

Imported soil required - no

Sludge application - 500-4,200 yd^3/acre (900-7,900 m^3/ha)

Equipment - track dozer, track loader

As shown above, sludge with solids contents as low as 3% may be received in such operations. Usually, such sludge is spray applied from a tank truck to a layer of refuse at the working face. The bulking ratio for a 3% solids sludge should be at least 7 tons of refuse to 1 wet ton of sludge (7 Mg of refuse to 1 wet Mg of sludge). Usually, only sludges with solids contents of 20% or more are mixed with refuse in such operations and fewer operational and environmental problems may be expected than when a 3% solids sludge is received. Also, less bulking agent is required and ratios as low as 4 tons of refuse to 1 wet ton of sludge (4 Mg of refuse to 1 Mg of sludge) are successfully practiced.

Also as shown above, sludge application rates for sludge/refuse mixtures compare favorably with other methods, despite the fact that sludge is not the only waste being disposed on the land. Application rates generally range from 500 to 4,200 yd^3 of sludge per acre (900 to 7,900 m^3 of sludge per ha).

3.6.3.2 Sludge/Soil Mixture

In a sludge/soil mixture operation, sludge is mixed with soil and applied as interim or final cover over completed areas of the refuse landfill. This is not strictly a sludge landfilling method since the sludge is not buried. However, it is a viable option for disposal of sludge at refuse landfills which has been performed and should be used in many cases. Relevant sludge and site conditions as well as design criteria are presented in the following tabulation.

Sludge and Site Conditions

Sludge solids content - $\geq 20\%$

Sludge characteristics - stabilized

Hydrogeology - deep or shallow groundwater or bedrock

Ground slopes - $< 5\%$

Design Criteria

Bulking required - yes

Bulking agent - soil

Bulking ratio - 1 soil:1 sludge

Cover soil required - no

Imported soil required - no

Sludge application - 1,600 yd^3/acre (3,000 m^3/ha)

Equipment - tractor with disc

One advantage of employing the sludge/soil mixture operation is that it removes sludge from the working face of the landfill where it may cause operational problems. Other advantages are that the mixture can be used to promote vegetation over completed fill areas; a savings in fertilizer can be realized; and siltation and erosion problems can be minimized.

One disadvantage of employing the sludge/soil mixture is that it generally has greater manpower and equipment requirements than would be incurred by landfilling the same sludge quantity at the working face. Another disadvantage is that since the sludge is not completely buried, odors may be more severe than for sludge/refuse mixtures. For this reason, only well stabilized sludges are recommended for use in sludge/soil mixture operations.

3.6.4 Sludge-Only or Codisposal

For a variety of reasons, consideration should be given to using codisposal methods for sludge disposal in lieu of sludge-only methods. The advantages of using an existing refuse landfill instead of a new sludge-only landfill include:

1. Shorter time delay. Processing of permits to dispose sludge at an existing refuse landfill will probably be quicker than processing permits for a new sludge-only site. Also since most or all of the site preparation required for sludge disposal is in place, delays for construction may not occur.
2. Less environmental impact. The environmental impact (odors, traffic, aesthetics, water) of one codisposal site will probably be less than the combined impacts from two separate sites.
3. Less public opposition. The public is less likely to resist an expansion in the operations of one site than it is to resist the operation of a new site.
4. Less cost. Due to economies of scale, the cost of one codisposal site will probably be less than the combined costs of two separate sites.

Obviously, there are several disadvantages for refuse landfill operators to consider when contemplating the receipt of sludge. These include:

1. Odors may increase somewhat depending upon the degree to which the sludge is stabilized.
2. Leachate may be generated sooner (if not already existing) or leachate quantities may increase (if already existing).
3. Operational problems may develop including equipment slipping or becoming stuck in sludge, or sludge being tracked around the site by equipment and haul vehicles.

Several other items should be considered by a refuse landfill before receiving sludge. These include:

1. Pertinent regulatory authorities should be consulted to ascertain whether sludge receipt is permissible.
2. Leachate collection and treatment systems may have to be enlarged (if existing) or installed (if not existing) to handle any increased leachate quantities.
3. Leachate treatment systems may have to be upgraded to handle any change in leachate quality.
4. A sufficient volume of refuse should be delivered to the site so that sufficient absorption of sludge moisture can occur.
5. Ideally, delivery of sludge and refuse should occur simultaneously. If not, storage capacity must be provided for either sludge or refuse so that the sludge can be mixed with refuse when landfilled.
6. Controlled dumping of refuse should occur to maximize its absorptive capacity with sludge. Such control may not be attainable when the public is allowed access to the working face.

3.6.5 Conclusion

In Section 3.6, an attempt has been made to identify and describe the major sludge landfilling methods. Sludge and site conditions as well as design criteria have been presented for each method. Chapter 4 will discuss the considerations and methodologies employed during the site selection process.

In practice, the selection of a landfilling method is an integral part of the site selection process. Indeed, it is imperative that the landfilling method be known prior to the final site selection since the acceptability of a given site is contingent upon the landfilling method to be employed. By the same token, the acceptability of a given landfilling method is contingent upon the site on which it is to be employed. And, of course, the acceptability of a given combination of landfilling method and site are in turn contingent upon the characteristics of the sludge received. Obviously then, a thorough investigation of sludge characteristics should be performed first, with concurrent investigations of sites and landfilling methods to follow.

Tables 3-7 and 3-8 are compilations of the conditions and criteria presented previously for each landfilling method. They are provided to give guidance during the investigation of alternative sites and landfilling methods. It is important to note that there may be no one best method for a given sludge or site. Rather, these considerations and criteria merely suggest sites and amenable landfilling methods that can simplify and improve the design and operation procedures required for an environmentally safe and cost-effective sludge landfill.

TABLE 3-7

SLUDGE AND SITE CONDITIONS

Method	Sludge solids content	Sludge characteristics	Hydrogeology	Ground slope
Narrow trench	15-28%	Unstabilized or stabilized	Deep groundwater and bedrock	<20%
Wide trench	≥20%	Unstabilized or stabilized	Deep groundwater and bedrock	<10%
Area fill mound	≥20%	Stabilized	Shallow groundwater or bedrock	Suitable for steep terrain as long as level area is prepared for mounding
Area fill layer	>15%	Unstabilized or stabilized	Shallow groundwater or bedrock	Suitable for medium slopes but level ground preferred
Diked containment	≥20%	Stabilized	Shallow groundwater or bedrock	Suitable for steep terrain as long as a level area is prepared inside dikes
Sludge/refuse mixture	≥3%	Unstabilized or stabilized	Deep or shallow groundwater or bedrock	<30%
Sludge/soil mixture	≥20%	Stabilized	Deep or shallow groundwater or bedrock	<5%

3.7 References

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4. General Pretreatment Regulations for Existing and New Sources of Pollution. U.S. Environmental Protection Agency. Federal Register. June 26, 1978. Part IV.

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TABLE 3-8
DESIGN CRITERIA

Method	Sludge solids content	Trench width	Bulking required	Bulking agent	Bulking ratio[a]	Cover Thickness Interim	Cover Thickness Final	Imported soil required	Sludge application rate (in actual fill areas)	Equipment
Narrow trench	15-20% 20-28%	2-3 ft. 3-10 ft.	No[c] No[c]	--- ---	---	------ ------	2-3 ft. 3-4 ft.	No	1,200-5,600 yd^3/acre	Backhoe with loader, excavator, trenching machine
Wide trench	20-28% ≥28%	10 ft. 10 ft.	No[c] No[d]	--- ---	---	------	3-4 ft. 4-5 ft.	No	3,200-14,500 yd^3/acre	Track loader, dragline, scraper, track dozer
Area fill mound	≥20%	---	Yes[d]	Soil	0.5-1 soil 1 sludge	3 ft.	3-5 ft.	Yes	3,000-14,000 yd^3/acre	Track loader, backhoe with loader, track dozer
Area fill layer	≥15%	---	Yes[d]	Soil	0.25-1 soil· sludge	0.5-1 ft.	2-4 ft.	Yes	2,000-9,000 yd^3/acre	Track dozer, grader, track loader
Diked containment	20-28% ≥28%	--- ---	No[b,c] No[b,d]	Soil Soil	0.25-0.5 soil: 1 sludge	1-2 ft.	3-4 ft.	Yes	4,800-15,000 yd^3/acre	Dragline, track dozer, scraper
Sludge/refuse mixture	≥3%	---	Yes[d]	Refuse	4-7 tons refuse: 1 wet ton sludge	0.5-1 ft.	2 ft.	No	500-4,200 yd^3/acre	Dragline, track loader
Sludge/soil mixture	≥20%	---	Yes	Soil	1 soil: 1 sludge	0.5-1 ft.	2 ft.	No	1,600 yd^3/acre	Tractor with disc, grader, track loader

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[a] Volume basis unless otherwise noted.

[b] But sometimes used.

[c] Land-based equipment

[d] Sludge-based equipment

1 ft = 0.305 m
1 yd^3 = 0.765 m^3
1 acre = 0.405 ha

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CHAPTER 4

SITE SELECTION

4.1 Purpose and Scope

The purpose of this chapter is to present the technical and economic considerations relevant to site selection and describe the methodologies for applying these considerations to the site selection process. The major divisions of this chapter are:

1. Site Considerations
    a. technical
    b. economic
2. Selection Methodology
3. Example of Methodology

The first part of this chapter is directed at those considerations which determine the suitability of a site for sludge landfilling. The landfilling method selected affects the suitability of a site and this is described in Chapter 3, Sludge Characteristics and Landfilling Methods. Public acceptance also affects the suitability of a site and this is described in Chapter 2, Public Participation Program. The second part of this chapter presents a methodology for site selection. The third part of this chapter includes an example of the methodology which will help the user to understand a general procedure for selecting a sludge landfill site.

It is important to emphasize the lead time necessary to select a site. The permitting process, evaluation, public review, purchase, and development of a landfill site may take a year or more. If the municipality does not correctly anticipate the time requirements, overuse and abuse of the existing landfill may result; at the very least the municipality will be forced into expensive storage or transportation of sludge.

4.2 Site Considerations

The technical considerations involved in selecting a sludge landfill site span many disciplines: land use planning, economics, engineering, and social and political fields. Among the technical considerations that must be considered in the evaluation process are:

1. Site life and size
2. Topography
3. Surface water
4. Soils and geology
5. Groundwater
6. Vegetation
7. Site access
8. Land Use
9. Archaeological or historical significance
10. Environmentally sensitive areas
11. Costs

4.2.1 Site Life and Size

The site life is determined by the size of the site, the quantity and characteristics of the sludge, and the landfilling method. In determining the required size, one must realize that not all the site can be filled. Thus, a site should be viewed in the following terms:

1. Gross area. The total area within the property boundaries.

2. Usable fill area. Excludes areas for buffers, access roads, and soil stockpiles. Typically the usable fill area can consume 50 to 70% of the gross area

Figure 4-1 demonstrates calculations used to determine the required site size given the site life, landfilling method, and daily sludge generation. Figure 4-2 on the other hand, calculates the site life given the usable area, sludge quantity, and landfilling method. Although in practice a municipality will usually not define the site life initially, a minimum acceptable life should be established, since start up costs become less significant over an extended period.

The landfilling method also has an impact on site life and size. For example, a wide trench method uses less land than a narrow trench operation, and thus provides a longer site life, all other factors being equal.

4.2.2 Topography

Since a relatively flat site could pond, and an excessively steep site could erode and create operational difficulties, sludge landfilling is

FIGURE 4-1

SAMPLE CALCULATION: AREA REQUIRED

Given:

1. Waste volume = 60 yd^3/day, 7 days/week, 29% solids sludge
2. Trench life = 10 yrs
3. Trench dimensions = 45 ft wide x 10 ft deep x 200 ft long
4. Trench spacing = 10 ft of solid ground between trenches
5. Buffer = 100 ft minimum, from usable filling area to property line

Solutions:

1. Trench volume needed:

   $(60\ yd^3/day) \times (365\ days/yr) \times (10\ yrs) = 219{,}000\ yd^3$

2. Number of trenches needed:

   $\frac{(219{,}000\ yd^3) \times (27\ ft^3/yd^3)}{(45\ ft \times 10\ ft \times 200\ ft)} \doteq 65.7$ trenches

3. Usable acreage needed:

   45 ft wide x 200 ft long trenches plus 10 ft between trenches
   = 55 ft x 210 ft gross space for each trench

   $(65.7\ trenches) \times (55\ ft \times 210\ ft\ trench) = 758{,}835\ ft^2$
   $\frac{(758{,}835\ ft^2)}{(43{,}560\ ft^2/acre} = 17.4$ acres

4. Minimum Gross Acreage Required:

   17.4 acres = 870 ft x 870 ft
   Minimum site size = (1,070 ft x 1,070 ft) + 25% for access roads, dumping pad, and miscellaneous uses = 33 acres

---

1 ft = 0.305 m
1 yd = 1.609 m
1 acre = 0.405 ha

FIGURE 4-2

SAMPLE CALCULATION: SITE LIFE AVAILABLE

Given:

1. Waste Volume = 45 yd^3/day, 7 days/week, 22% solids sludge
2. Usable fill area = 6 acres
3. Trench dimensions = 10 ft wide x 5 ft deep x 120 ft long
4. Trench spacing = 5 ft of solid ground between trenches

Calculations:

1. Number of available trenches:

   Each trench will have area = 15 ft x 125 ft = 1,875 ft^2

   Total acreage = 6 acres = 261,360 ft^2

   Number of trenches = $\frac{261{,}360\ ft^2)}{1{,}875\ ft^2} = 139$ trenches

2. Trench volume available:

   $(139\ trenches) \times \frac{(10\ ft \times 5\ ft \times 120\ ft)}{trench} \times \frac{1\ yd^3}{27\ ft^3} = 30{,}089\ yd^3$

3. Site life:

   $\frac{30{,}889\ yd^3}{45\ yd^3/day} = 686$ days = 1.9 yrs

---

1 ft = 0.305 m
1 yd = 1.609 m
1 acre = 0.405 ha

usually limited to areas that have slopes greater than 1% and less than 20%. Again, the landfilling method determines to some extent what operations are amenable to a given topography.

4.2.3 Surface Water

The amount and nature of surface water bodies on a landfill are a significant factor in site selection. The existing bodies of surface water and drainage on or near proposed sites should be mapped and their current and future use considered. Certain areas such as wetlands and flood plains should be avoided if at all possible since they are environmentally sensitive areas [1]. Where it is necessary to use either wetlands or floodplains the owner should be prepared to perform extensive designs, provide operational controls of runoff and infiltration, prepare environmental reports, and spend additional time obtaining approvals from regulatory agencies.

In addition, the Clean Water Act of 1977 requires that all point source discharges of pollutants (e.g., surface leachate or leachate treatment effluent) must comply with NPDES permits issued for the facility. Thus, selection of a site with surface water can compound design and operational difficulties and increase the difficulty in securing a permit. This should be considered during the selection process.

4.2.4 Soils and Geology

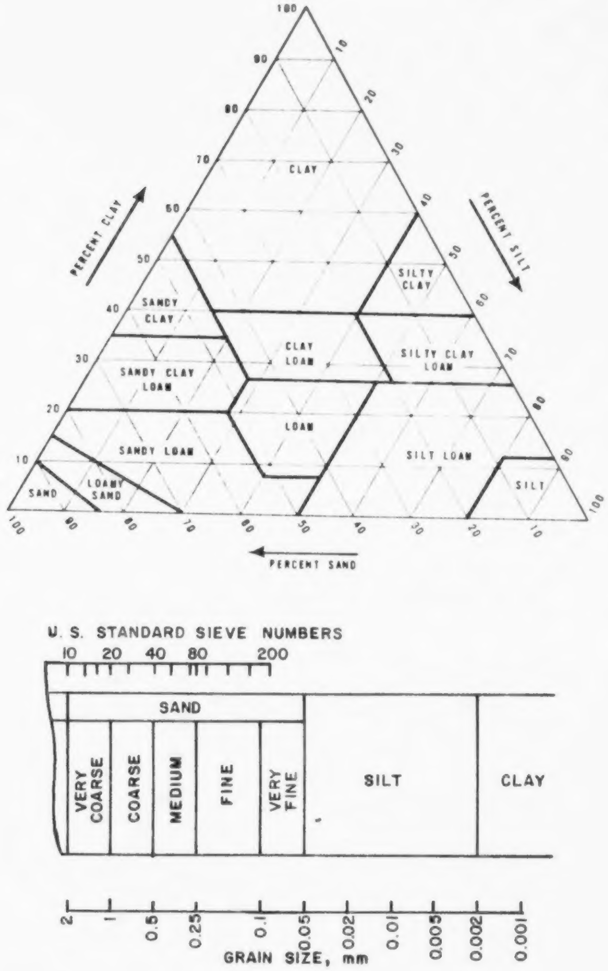
The role of soil in sludge landfills is to provide cover, attenuate potential contaminants, control runoff and leachates, and serve as a bulking agent (if the sludge characteristics and landfilling method warrant). The chemical and physical/hydraulic properties of a soil determine how effective it will be in performing these roles. Accordingly, relevant soil properties that should be noted during the selection process are:

1. Physical/hydraulic properties
    a. Texture
    b. Structure
    c. Soil depth and quantity
    d. Permeability/transmissivity
2. Chemical properties
    a. pH
    b. Cation exchange capacity (CEC)

In general, a desirable geology will have some combination of deep and fine-textured soils. The finer the soil, the less depth needed. Sites operating on clay and clay loams, for instance, have operated successfully with as little as 2 to 5 ft (0.6 to 1.5 m) of soil separating sludge deposits from the highest groundwater elevations. Other soils require a considerably greater thickness. The amount and type of soil needed depends on the landfilling method and the characteristics of the sludge disposed [2]. Figure 4-3 gives the textural classifications used by the U.S. Department of Agriculture, Soil Conservation Service (SCS).

FIGURE 4-3

SOIL TEXTURAL CLASSES AND GENERAL TERMINOLOGY USED IN SOIL DESCRIPTIONS



Permeability is dependent on the soil texture and structure. Again, fine-grained, poorly structured soils have the lowest permeabilities. Table 4-1 and Figure 4-4 give qualitative ranges for classifying soil permeabilities. Depending on the sludge characteristics, a moderately low to low permeability soil is desirable for a sludge landfill site, although proper landfilling has been observed in relatively permeable soils. As with texture, there is an inverse relationship between the required soil thickness and soil permeability.

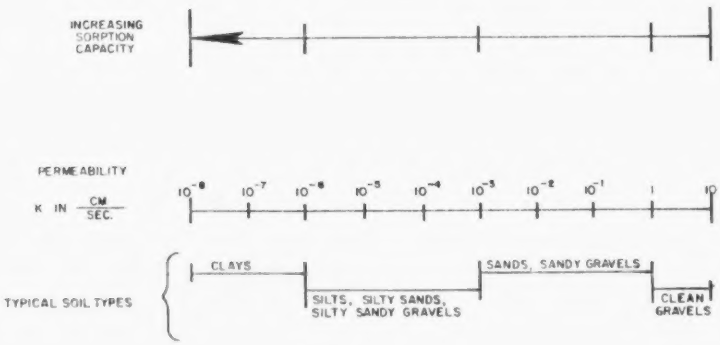
TABLE 4-1

PERMEABILITY CLASSES FOR SATURATED SOIL [3]

Soil permeability (cm/s)	Class
$<4.2 \times 10^{-5}$	Very slow
4.2×10^{-5} to 1.4×10^{-4}	Slow
1.4×10^{-4} to 4.2×10^{-4}	Moderately slow
4.2×10^{-4} to 1.4×10^{-3}	Moderate
1.4×10^{-3} to 4.2×10^{-3}	Moderately rapid
4.2×10^{-3} to 1.4×10^{-2}	Rapid
$>1.4 \times 10^{-2}$	Very rapid

FIGURE 4-4

SOIL PERMEABILITIES AND SORPTIVE PROPERTIES OF SELECTED SOILS



The climate also influences the soil requirements of a specific site. In an area with high rainfalls, for example, soils with permeabilities that are lower than the sludge permeabilities could result in the so-called "bathtub" effect: a situation in which water accumulates in the trench areas and cannot drain. If impermeable soils are to be used in these areas, it may be necessary to install leachate collection systems.

The pH and cation exchange capacity (CEC) influence the ability of soils to attenuate cations [3]. Heavy metals are frequently held by alkali soils. The CEC is determined to a large extent by the clay content of the soil but it increases in direct proportion to the pH dependent charged particles (hydrous metal oxides and organic matter) in the soil. Table 4-2 shows typical ranges for CEC values in various soils. Soils with higher CEC values are more efficient at removing cations and are therefore desirable at a sludge landfill site. Other significant considerations concerning soils are compaction characteristics, drainage, and slope stability. These are summarized in Figure 4-5.

TABLE 4-2

TYPICAL RANGES OF CATION EXCHANGE CAPACITY OF VARIOUS TYPES OF SOILS [3]

Soil type	Range of CEC, meq/100 g
Sandy soils	1 to 10
Silt loams	12 to 20
Clay and organic soils	Over 20

The structural and mineralogical characteristics of the aquifer should be delineated so that the potential for contamination can be accurately assessed. Faults, major fractures, and joint sets should be identified for candidate sites. Where these features are in hydraulic contact with an aquifer, contamination could occur. Karst terrains and other solutional formations should be avoided. In general, limestone, dolomite,

FIGURE 4-5

UNIFIED SOIL CLASSIFICATION SYSTEM AND CHARACTERISTICS PERTINENT TO SLUDGE LANDFILLS [4]

Major Divisions		SYMBOL			NAME	Potential Frost Action	Drainage Characteristics*	Value for Embankments	Permeability cm per sec	Compaction Characteristics†	Std AASHO Max Unit Dry Weight lb per cu ft‡	Requirements for Seepage Control
		Letter	Hatching	Color								
COARSE-GRAINED SOILS	GRAVEL AND GRAVELLY SOILS	GW	∘	RED	Well-graded gravels or gravel-sand mixtures, little or no fines	None to very slight	Excellent	Very stable, pervious shells of dikes and dams	$k > 10^{-2}$	Good, tractor, rubber-tired, steel-wheeled roller	125-135	Positive cutoff
		GP	•		Poorly graded gravels or gravel-sand mixtures, little or no fines	None to very slight	Excellent	Reasonably stable, pervious shells of dikes and dams	$k > 10^{-2}$	Good, tractor, rubber-tired, steel-wheeled roller	115-125	Positive cutoff
		GM	▥	YELLOW	Silty gravels, gravel-sand-silt mixtures	Slight to medium	Fair to poor Poor to practically impervious	Reasonably stable, not particularly suited to shells, but may be used for impervious cores or blankets	$k = 10^{-3}$ to 10^{-6}	Good, with close control, rubber-tired, sheepsfoot roller	120-135	Toe trench to none
		GC	▨		Clayey gravels, gravel-sand-clay mixtures	Slight to medium	Poor to practically impervious	Fairly stable, may be used for impervious core	$k = 10^{-6}$ to 10^{-8}	Fair, rubber-tired, sheepsfoot roller	115-130	None
	SAND AND SANDY SOILS	SW	∘	RED	Well-graded sands or gravelly sands, little or no fines	None to very slight	Excellent	Very stable, pervious sections, slope protection required	$k > 10^{-3}$	Good, tractor	110-130	Upstream blanket and toe drainage or wells
		SP	•		Poorly graded sands or gravelly sands, little or no fines	None to very slight	Excellent	Reasonably stable, may be used in dike section with flat slopes	$k > 10^{-3}$	Good, tractor	100-120	Upstream blanket and toe drainage or wells
		SM	▥	YELLOW	Silty sands, sand-silt mixtures	Slight to high	Fair to poor Poor to practically impervious	Fairly stable, not particularly suited to shells but may be used for impervious cores or dikes	$k = 10^{-3}$ to 10^{-6}	Good, with close control, rubber-tired, sheepsfoot roller	110-125	Upstream blanket and toe drainage or wells
		SC	▨		Clayey sands, sand-clay mixtures	Slight to high	Poor to practically impervious	Fairly stable, use for impervious core for flood control structures	$k = 10^{-6}$ to 10^{-8}	Fair, sheepsfoot roller, rubber-tired	105-125	None
FINE-GRAINED SOILS	SILTS AND CLAYS LL IS LESS THAN 50	ML	▥	GREEN	Inorganic silts and very fine sands rock flour, silty or clayey fine sands or clayey silts with slight plasticity	Medium to very high	Fair to poor	Poor stability, may be used for embankments with proper control	$k = 10^{-3}$ to 10^{-6}	Good to poor, close control essential, rubber-tired roller, sheepsfoot roller	95-120	Toe trench to none
		CL	▨		Inorganic clays of low to medium plasticity, gravelly clays, sandy clays, silty clays, lean clays	Medium to high	Practically impervious	Stable, impervious cores and blankets	$k = 10^{-6}$ to 10^{-8}	Fair to good, sheepsfoot roller, rubber-tired	95-120	None
		OL	▥		Organic silts and organic silt-clays of low plasticity	Medium to high	Poor	Not suitable for embankments	$k = 10^{-4}$ to 10^{-6}	Fair to poor, sheepsfoot roller	80-100	None
	SILTS AND CLAYS LL IS GREATER THAN 50	MH	▥	BLUE	Inorganic silts, micaceous or diatomaceous fine sandy or silty soils, elastic silts	Medium to very high	Fair to poor	Poor stability, core of hydraulic fill dam, not desirable in rolled fill construction	$k = 10^{-4}$ to 10^{-6}	Poor to very poor, sheepsfoot roller	70-95	None
		CH	▨		Inorganic clays of high plasticity, fat clays	Medium	Practically impervious	Fair stability with flat slopes, thin cores, blankets and dike sections	$k = 10^{-6}$ to 10^{-8}	Fair to poor, sheepsfoot roller	75-105	None
		OH	▨		Organic clays of medium to high plasticity, organic silts	Medium	Practically impervious	Not suitable for embankment	$k = 10^{-6}$ to 10^{-8}	Poor to very poor, sheepsfoot roller	65-100	None
HIGHLY ORGANIC SOILS		Pt	≋	Orange	Peat and other highly organic soils	NOT RECOMMENDEL FOR SANITARY LANDFILL CONSTRUCTION						

*Values are for guidance only design should be based on test results

†The equipment listed will usually produce the desired densities after a reasonable number of passes when moisture conditions and thickness of lift are properly controlled

‡Compacted soil at optimum moisture content for Standard AASHO (Standard Proctor) compactive effort

and heavily fractured crystalline rock are less desirable than sedimentary and consolidated alluvial bedrock.

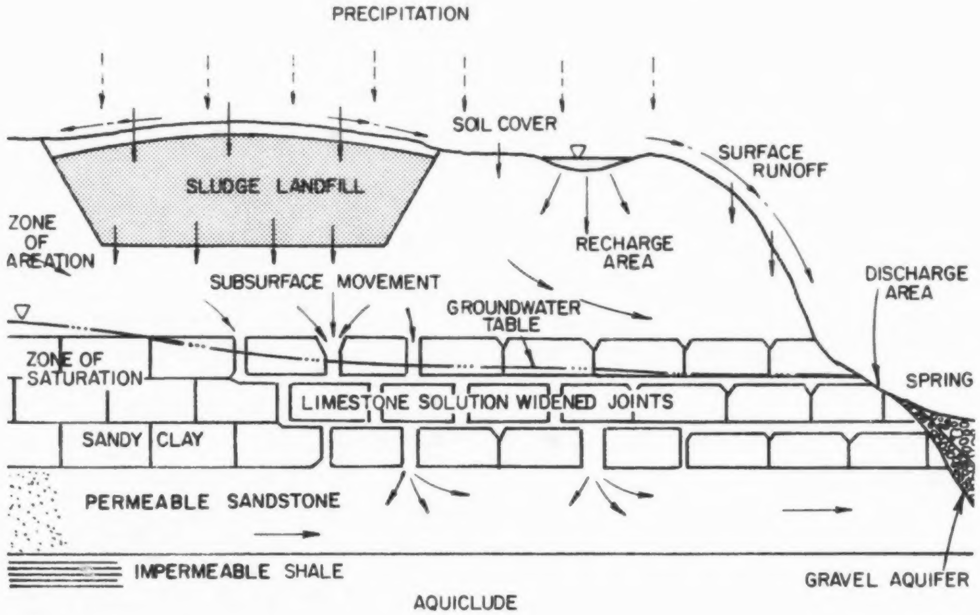
4.2.5 Groundwater

Groundwater can generally be classified into two components. The first is that groundwater located within the zone of saturation. The second is known as interstitial water and includes groundwater located in the zone of aeration. For the purposes of this section, discussions of groundwater are directed toward water within the zone of saturation.

In assessing the suitability of a site for sludge landfilling, collection and evaluation of data on local aquifers is essential. The information should include depth to groundwater (including historical highs and lows), the hydraulic gradient, the quality of the groundwater, its current and projected use, and the location of primary recharge zones. Figure 4-6, a schematic representation of the hydrogeological cycle, illustrates these principles.

FIGURE 4-6

HYDROGEOLOGICAL CYCLE [4]



Sludge should not be placed where there is a potential for direct contact with the groundwater table. Also, major recharge zones should be eliminated from consideration, particularly sole source aquifers. As much distance as possible should be maintained between the bottom of the fill and the highest known level of groundwater.

Sources of data on groundwater quality and movement include the U.S Geological Survey (USGS) "Groundwater Data Network", local well drillers, State geological surveys, State health departments, other State environmental and regulatory agencies, and samplings from nearby wells. The USGS also publishes an annual report entitled "Groundwater Levels in the United States" in the Water-Supply Paper Series. The data for this paper is derived from some 3,500 observation wells located across the nation.

If necessary, further background information on groundwater should be collected by performing on-site drilling. The following information is relevant to evaluating a site:

1. Groundwater elevations and fluctuations
2. Hydraulic gradient
3. Groundwater quality

The hydraulic gradient is equivalent to the slope of the groundwater table (or the slope of the piezometric surface for an artesian aquifer). Determining the hydraulic gradient of the site is important in ascertaining the rate and amount of groundwater movement and whether or not hydraulic connections to surrounding aquifers exist. The direction of groundwater flow (and thus the hydraulic gradient) can be determined by noting the depth to groundwater in nearby wells or borings, calculating the elevation of the groundwater, and drawing contour lines that connect wells of equal groundwater elevations.

At least three wells--and normally more--are needed to determine the direction of groundwater flow. Usually large sites, sites with complex hydrogeology, and/or relatively flat sites require more borings than small sites. An experienced hydrogeologist should participate in the research and exploratory drilling to interpret field data. He can recommend the number, location, and type of exploratory wells needed. Table 4-3 summarizes log tests and the information available from them.

4.2.6 Vegetation

The amount and type of vegetation on a prospective site should be considered in the selection process. Vegetation can serve as a buffer and

TABLE 4-3

SUBSURFACE LOGGING INFORMATION OBTAINED BY VARIOUS METHODS [3]

Method	Operation	Information
Drillers' log	Observe well cuttings during drilling	Rock contacts, thickness, description, or type texture. Samples for laboratory tests. Common method.
Drilling-time log	Observe drilling time	Rock texture, porosity.
Resistivity log	Measure electrical resistivity of media surrounding encased hole	Specific resistivity of rocks porosity, packing, water resistivity, moisture content, temperture, groundwater quality. Correlate with samples for best results. Common method.
Potential log	Measure natural electric potential, or self-potential	Permeable or impermeable, groundwater quality. Common method.
Temperature log	Measure temperature	Groundwater circulation, leakage.
Caliper log	Measure hole diameter	Hole diameter, rock consolidation, caving zones, casing location.
Current log	Measure current	Groundwater flow velocity, circulation, leakage.
Radioactive log	Measure attenuation of gamma and neutron rays	Consolidation, porosity, moisture content. Common in soil studies, clay or nonclay materials.

reduce dust, noise, odor and visibility. However, where extensive logging and/or clearing of vegetation is necessary, it can increase costs prohibitively.

4.2.7 Site Access

The haul routes to the prospective sites should utilize major highways to the maximum extent possible. Potential routes should be driven and studied to determine the physical adequacy of roadways for truck traffic; the approximate number of residences, parks, and schools fronting the roads; and the probable impact on traffic congestion.

4.2.8 Land Use

The zoning of each prospective site should be considered from the perspective of both current and future standards. The appropriate county or municipal zoning authority should be contacted to determine zoning status or restrictions as they pertain to each site. Completed site use of the sludge landfill should be considered early in the selection process and evaluated relative to future zoning (see Chapter 8, Completed Site).

Regional development should also be considered in site selection, and existing master plans for the area should be consulted. The evaluation of current and future development may present the opportunity for a more strategically centralized location of the sludge landfill. Moreover, the projected rate of industrial and/or municipal development and its location affect the site size which will be needed to meet projected demands.

4.2.9 Archaeological or Historical Significance

The archaeological or historical significance of the land involved in a potential site should be ascertained. The determination of the historical status of a potential site is usually addressed in an environmental impact report and should be performed by a qualified archaeologist/anthropologist. Due to the expense involved in such studies, archaeological and historical investigations should be limited to the top ranking candidates. Any finds of significance in relation to the archaeology or history of the site must be accommodated before the site can be approved and construction can begin.

4.2.10 Environmentally Sensitive Areas

The Classification Criteria for Solid Waste Disposal Facilities [1] now being promulgated by EPA identify five environmentally sensitive areas. These include:

1. Wetlands
2. Flood plains
3. Permafrost areas
4. Critical habitats of endangered species
5. Recharge zones of sole source aquifers

In general, sludge landfills should not be located in environmentally sensitive areas when feasible alternatives exist since both the technical and administrative measures required will probably be more complex. In addition, permits may be required for sludge landfilling in such areas (including wetlands and critical habitats).

4.2.11 Costs

Early in the selection process an economic screening of sites should be performed to determine relative costs. In order to obtain a meaningful figure that can be used to compare sites, capital and operating costs should be estimated. This estimate may be computed as shown below. This discussion does not account for the time value of money. For most sites, particularly long-lived sites, this will tend to favor the selection of sites with high capital costs over sites with relatively higher operating costs. In some cases, it may be necessary to compute amortized capital costs. However, the process described below is less complex and will be accurate in the vast majority of cases.

1. Determine the capital costs (C) in dollars over the life of the site. This should include primarily:
    a. Land aquisition
    b. Site preparation
    c. Equipment purchase
2. Determine site life (L) in years.
3. Compute unit capital cost (P_1) in dollars/yd^3 of sludge based on proposed annual sludge quantity (Q) in yd^3/yr.

$$P_1 = \frac{C}{LQ}$$

4. Determine total operating cost (O) in dollars over one year. This should include primarily:
    a. Labor
    b. Equipment fuel, maintenance, and parts
    c. Utilities
    d. Laboratory analysis of water samples
    e. Supplies and materials
    f. Miscellaneous and other

5. Compute unit operating cost (P_2) in dollars/yd^3 of sludge based on proposed annual sludge quantity (Q) in yd^3/yr.

$$P_2 = \frac{O}{Q}$$

6. Determine total hauling cost (H) in dollars over one year.

7. Compute unit haul cost (P_3) in dollars/yd^3 of sludge based on proposed annual sludge quantity (Q) in yd^3/yr.

$$P_3 = \frac{H}{Q}$$

8. Compute total annual cost (T) in dollars/yd^3 of sludge.

$$T = P_1 + P_2 + P_3$$

4.3 Site Selection Methodology

A site selection process may consist of the following stages:

1. Initial assessment of sites
2. Screening of candidate sites
3. Final site selection

Sections 4.3.1, 4.3.2, and 4.3.3 outline a selection procedure that has been used. This procedure is summarized in Figure 4-7. Smaller sites may not require a selection process as detailed as the one presented below.

4.3.1 Initial Assessment of Sites

Step 1-1: Determine regulatory constraints (Federal, State, local) based on:

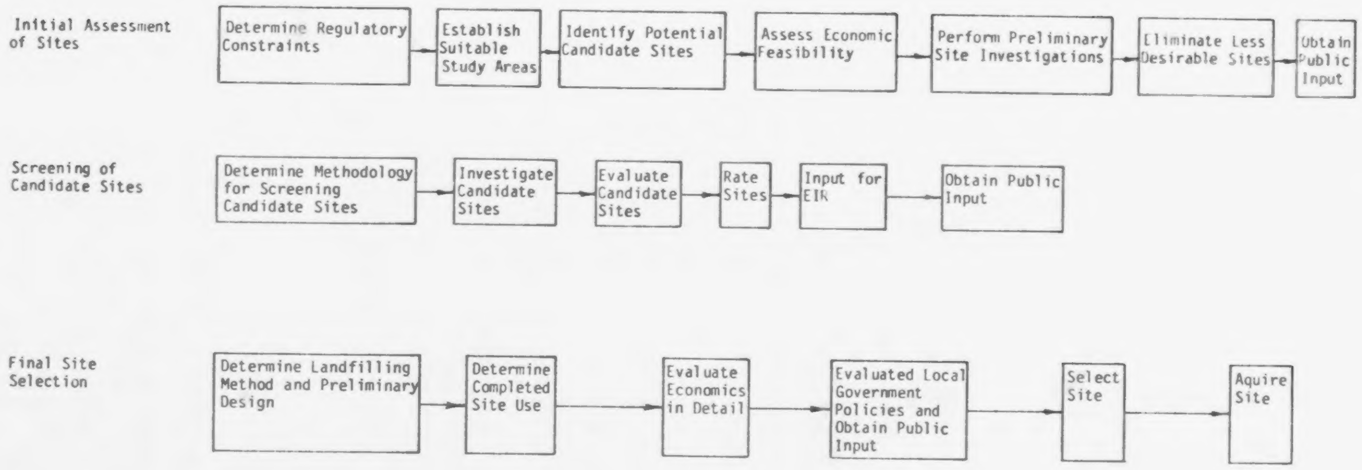
1. Physical limitations (groundwater depth, maximum slope)

2. Demographical limitations (distance to nearest residence, land-use factors)

3. Political limitations (public reaction, special interest groups, budget management)

FIGURE 4-7

SITE SELECTION METHODOLOGY


Initial Assessment of Sites
Determine Regulatory Constraints
Establish Suitable Study Areas
Identify Potential Candidate Sites
Assess Economic Feasibility
Perform Preliminary Site Investigations
Eliminate Less Desirable Sites
Obtain Public Input
Screening of Candidate Sites
Determine Methodology for Screening Candidate Sites
Investigate Candidate Sites
Evaluate Candidate Sites
Rate Sites
Input for EIR
Obtain Public Input
Final Site Selection
Determine Landfilling Method and Preliminary Design
Determine Completed Site Use
Evaluate Economics in Detail
Evaluated Local Government Policies and Obtain Public Input
Select Site
Aquire Site

Step 1-2: Establish suitable study areas:

1. Determine maximum radius of study area based on haul distance(s) from wastewater treatment plant(s) and/or centroid of potential service area.
2. Use transparent (mylar) overlays to designate areas which have:
   a. inappropriate slope
   b. dense population
   c. undesirable geology (karst, fractured bedrock formations, faults)
   d. undesirable soil (shallow, high organics, permafrost areas)
   e. unsuitable surface or groundwater conditions (flood plains, bogs, areas of ponding, marshes, recharge zones of aquifers)
3. Place shaded mylars of these low suitability areas on study area map. The unshaded area may be considered generally suitable for landfilling.

Step 1-3: Identify potential candidate sites:

1. Inform local realtors
2. Investigate past site inventories
3. Study maps or aerial photographs
4. Traverse roads in high probability areas for "For Sale" or "For Lease" signs

Step 1-4: Assess economic feasibility (ballpark estimate based on experience, rule of thumb, judgement) including:

1. Haul distances
2. Rough estimate of site development cost
3. Quantity of sludge
4. Operating hours per week for equipment and personnel

Step 1-5: Perform preliminary site investigations using existing information (see Chapter 5, Design) and tabulate information. Pertinent information includes:

1. Location (drainage basin)
2. Land use(on and near site)
3. Haul distance and routes
4. Topography
5. Soil characteristics
6. Area of site

Step 1-6: Eliminate less desirable sites based on regulatory and economic constraints and technical considerations.

Step 1-7: Obtain public input via the public participation program (see Chapter 2). For example, a kick-off meeting would help to determine the attitude of the citizenry early in the process. Area residents also may assist in identifying candidate sites.

4.3.2 Screening of Candidate Sites

Step 2-1: Determine methodology for screening candidate sites in terms of the considerations listed below. Designate the degree of detail required to fulfill regulatory requirements. Designate a screening committee of qualified personnel. The methodology may include scoring systems and other subjective analyses [5]. Again, the evaluation presented below may be more extensive than necessary for small sludge landfills.

1. Technical considerations
    - a. haul distance
    - b. site life and size
    - c. topography
    - d. surface water
    - e. soils and geology
    - f. groundwater
    - g. soil quantity and suitability
    - h. vegetation

i. environmentally sensitive areas
j. archaeological or historical significance
k. site access
l. land use

2. Economic considerations

3. Public acceptance considerations

Step 2-2: Investigate 4 to 6 candidate sites and identify site specific problems. Field investigations (see Chapter 5, Design) may be appropriate to supplement information from existing sources. However, the degree of detail and intensity of investigation will vary from site to site.

Step 2-3: Evaluate sites. The sites may be evaluated in terms of the potential adverse impact on the environment. A scoring system similar to the one described in Section 4.4 may be useful in quantitatively evaluating the candidate sites.

Step 2-4: Rate sites. The rating is based on technical considerations.

Step 2-5: Input site selection findings of top site(s) into an environmental impact report (if required).

Step 2-6: Obtain public input.

4.3.3 Final Site Selection

Step 3-1: Prior to final site selection, the landfilling method and preliminary design should be ascertained for each site. These designs should be compatible with sludge and site characteristics (see Section 3.6). Preliminary drawings are prepared in this phase.

Step 3-2: Evaluate alternative completed site uses and determine use for each candidate site.

Step 3-3: Evaluate economics in detail

1. Site capital cost
2. Site operating cost
3. Hauling cost

Step 3-4: Evaluate local government policies and obtain public input. A public hearing may be scheduled to receive final comments from local government officials and the public.

Step 3-5: Select site and list alternative sites.

Step 3-6: Acquire site. The following options are available:

1. Option to purchase and subsequent execution (await site approval)
2. Outright purchase (after site approval by regulatory agency and local jurisdiction)
3. Lease
4. Condemnation and/or other court action
5. Land dedication

4.4 Example of Methodology

This section presents an example of a methodology used for selecting a landfill site. This example includes initial assessment, screening, and final selection procedures. The procedures in this example employ numerical scoring systems. However, in some cases it may be more appropriate to use a qualitative system (e.g., using terms such as suitable, marginally suitable, not suitable in lieu of numerical ratings). In this example, the study area was a large county in the mid-Atlantic region.

4.4.1 Initial Assessment of Sites

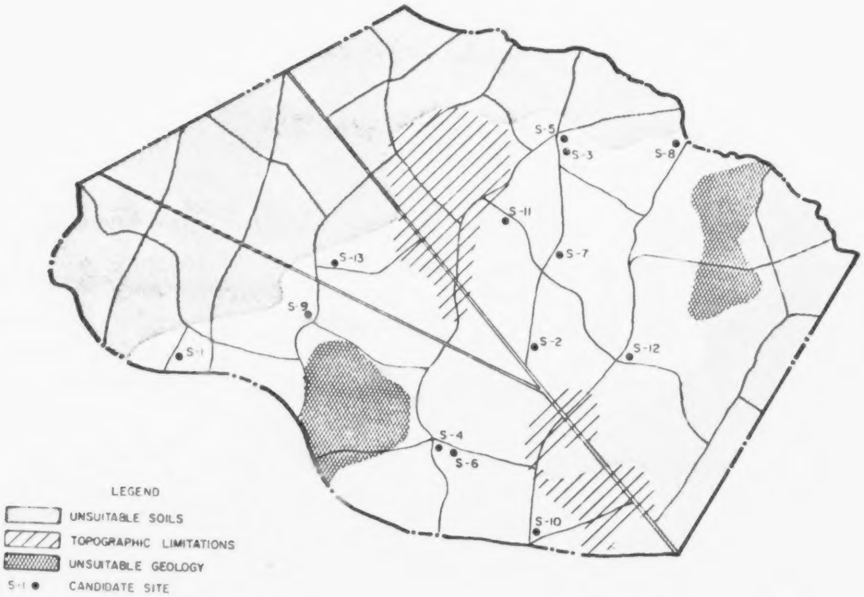
The initial step was to use overlays to narrow the study area to that portion of the county where technically suitable sites were most likely to be found.

1. Overlay No. 1. Shaded areas having questionable soils. The soils were evaluated in terms of soil permeability and runoff characteristics. The SCS District Manager and the Cooperative Extension Service were sources for this information.
2. Overlay No. 2. Shaded areas containing possible topographical limitations. These included flood plains and a small watershed which drained to a vital drinking water supply.
3. Overlay No. 3. Shaded areas having questionable geology. State geologists were consulted to determine areas where shallow soil which covers fractured bedrock existed.

The overlays were placed over a county map and the unshaded areas were considered generally suitable for sludge landfilling (see Figure 4-8).

FIGURE 4-8

INITIAL ASSESSMENT WITH OVERLAYS



After identifying all feasible sites (13 in this case), a preliminary investigation of technical data was performed. The results were tabulated in Table 4-4. Based on the information compiled in Table 4-4, these 13 sites were then evaluated relative to the criteria listed in Step 1-5 of Section 4.3.1. Based on this evaluation, 9 of the sites were eliminated from futher considerations. The 4 remaining sites were identified as S-5, S-10, S-11, and S-13.

4.4.2 Screening of Candidate Sites

The screening process began with the collection of more detailed information on the remaining 4 sites. This data is compiled in Table 4-5. A scoring system was then applied as shown in Table 4-6 using the following considerations.

1. Principal objectives of sludge landfills. The etablishment and use of the site was based on certain objective. Objectives were developed so that they were attainable, and the degree of attainment was measurable. The scoring system employed contained five principal objectives.
2. Rating of objectives by order of importance. The objectives were listed in order of importance, and a value was assigned to each objective to reflect its relative importance. Once this was accomplished, experience showed that many of the originally listed objectives appeared insignificant and were therefore discarded.
3. Criteria. Having listed the objectives, criteria which measured the ability of a site to attain that objective was then developed.
4. Relative ability of criteria to fulfill objective. The criteria for each objective then was assigned numerical values that reflected their relative ability to measure most exactly the attainment of the objective, rather than their individual significance.
5. Maximum score. Based on values in columns (2) and (4), the maximum score was calculated for each criterion. For example the objective of public health has a rating of 1,000. The criteria of a groundwater pollution hazard rates 10 out of a total of 34 total points for all public health criteria. Therefore, (10/34)x(1,000) = a maximum score of 244 points
6. Prospective landfill sites. All sites were compared relative to one criterion by assigning a numerical value (rating) that reflected the site's ability to satisfy the criterion being examined. (If a site could not meet the objective being

TABLE 4-4

PRELIMINARY INVESTIGATIONS FOR INITIAL ASSESSMENT

Map ref.	Site name/ location	Zoning	Site	Adjacent areas	Access (mi)	Haul distance (mi)	Available[a]	General terrain	Characteristics	Cover soil adequacy[b]	Estimated Costs ($)		Site area total/ usable (acres)	Drainage Basin
											Site purchase and preparation	Haul each year		
S-1	North Shore Road Site	Rural Residential	Farmland Vacant land	Farmland Residential	Highway-20 Residential-2 Rural-3	25	P,T	Gently sloping to hilly	Well drained, fine sands and silty materials, some clay	F-G	310,000	125,000	15/10	Middle Run
S-2	Fulton Road Site	Agricultural	Vacant land	Vacant land Residential Commercial	Main access-7 Rural-3	10	—	Flat to steeply sloping	Silty to sands, gravel	F	280,000	100,000	12/8	Middle Run
S-3	Chaffee Avenue Site	Forest & Farming	Farmland Vacant land	Vacant land Residential	Rural-5	5	P,T	Gently to moderately sloping	Silty sands and sands	F	360,000	25,000	20/12	East Branch
S-4	Greenville Road Site	Rural Residential Flood plain	Vacant land	Vacant land Residential	Residential-10 Main access-5 Rural-3	18	P,T	Gently sloping	Silty clayey sands, some gravel and clay	P	250,000	90,000	17/9	North River
S-5	Alton Street Site	Agricultural	Borrow pit Vacant land	Vacant land Industrial Residential	Rural-3	3	P,T,W,S	Hilly with steep slopes	Silty sands & sands with some clay	G-E	335,000	15,000	20/14	East Branch
S-6	Salem Road Site	Forest & Farming Rural Residential	Vacant land	Vacant land Residential	Highway-20 Rural-2	22	—	Gently sloping	Sandy loam overlying clay	F	420,000	110,000	27/15	Middle Run
S-7	Windsor Avenue Site	Forest & Farming	Vacant land	Vacant land Residential	Residential-5 Rural-2	7	P,T,W	Hilly with steep slopes	Fine sand, silts, and some clay	F	250,000	35,000	20/12	East Branch
S-8	La Plata Road Site	Agricultural	Vacant land Farmland	Vacant land Farmland	Rural-9	9	P,T	Gently to moderately sloping	Glacial till with shallow bedrock	G-E	200,000	45,000	15/11	Middle Run
S-9	Newman Street Site	Agricultural	Vacant land Borrow pit	Vacant land Farmland Residential	Residential-5 Rural-12	17	—	Flat to steeply sloping	Sands, silty sands	G	225,000	85,000	17/10	North River
S-10	Hunter Road Site	Forest & Farming	Vacant land	Vacant land Residential Golf Course	Main access-20 Residential-7 Rural-3	30	—	Gently sloping to hilly	Fine silt, sand and gravels	E	520,000	150,000	37/25	Beaver River
S-11	Harrington Blvd. Site	Industrial	Borrow pit Vacant land	Borrow pits Vacant land Industrial Residential	Main access-2 Rural-3	5	P,T,W,S	Hilly and irregular	Fine sand and silty sands, clay	F-G	300,000	25,000	25/19	East Branch

TABLE 4-4
(continued)

Map ref.	Site name/ location	Zoning	Site	Adjacent areas	Access (mi)	Haul distance (mi)	Available[a]	General terrain	Characteristics	Cover soil adequacy[b]	Estimated Costs ($) Site purchase and preparation	Estimated Costs ($) Haul each year	Site area total/ usable (acres)	Drainage Basin
S-12	East Avenue Site	Industrial Residential	Borrow pits Vacant land	Vacant land Residential Farmland City landfill	Main access-9 Rural-2	11	—	Hilly and irregular	Fine to course sands with some clay	F	200,000	55,000	10/6	Middle Branch
S-13	Gifford Road Site	Agricultural	Vacant land	Farmland Vacant land Residential	Residential-2 Rural-13	15	—	Gently sloping	Some fine sands and silts over-lying clay	E	720,000	75,000	30/20	North River

Key:

[a] P = power; T = telephone; W = water; S = sewer

[b] P = poor; F = fair; G = good; E = excellent

1 ft = 0.305 m
1 mi - 1.609 km
1 ac = 0.405 ha

TABLE 4-5

INVESTIGATION OF CANDIDATE SITES FOR SCREENING

Map ref.	Site name/ location	Site description	Site area total/ usable (acres)	Haul distance (mi)	Depth to ground-water (ft)	Surface water on-site	Downstream water use	Soil types	Geology	Distance to nearest residence (ft)	Vegetation type/density	Possible effect on site on use of adjoining areas+
S-5	Alton Street Site	Abandoned Borrow pit	20/14	3	10-20	4 intermittent streams 1 flowing stream	Bottstown water supply, 8 mi	Mb manor silty loam	Fractured limestone at 6 ft	8 000	Tall oak trees, 20% of total area	N,M
S-10	Hunter Road Site	Gently sloping vacant land	37/25	30	8-15	2 flowing streams	Recreation	Sa Sassafras Fine sandy loam	Sandstone/ shale	1 000	Thick brush, 30% of total area	N,M
S-11	Harrington Bvld. Site	Borrow pit	25/19	5	5	1 small on-site pond	None	Penn fine sandy loam	Sandstone/ shale	1 000	Few tall trees, 20% of total area	M,U
S-13	Gifford Road Site	Gently sloping vacant land	30/20	15	30	2 intermittent streams	None	Ln Lunt Fine sandy loam	Sandstone	5 000	Tall trees, 30% of total area	N

Key:
N = none; M = minor degradation; U = undesirable

1 ft = 0.305 m
1 mi - 1.609 km
1 ac = 0.405 ha

TABLE 4-6

RATING OF SITES FOR SCREENING USING SCORING SYSTEM

Principal Objectives of Sludge Landfill	Rating of Objectives By Order of Importance	Criteria	Relative Ability of Criteria to Fulfill Objective	Max Score	S-5		S-10		S-11		S-13	
					Rating	Score	Rating	Score	Rating	Score	Rating	Score
The site must not endanger public health.	1,000	Groundwater pollution hazard	10	294	7	206	5	147	9	265	9	265
		Gas hazard	8	235	6	176	6	176	8	235	8	235
		Groundwater pollution potential	8	235	5	147	4	118	7	206	7	206
		Surface water pollution potential and hazard	6	176	1	29	1	29	2	59	2	59
		Dust, noise, and odor hazards	1	29	1	29	1	29	1	29	1	29
		Traffic access hazard potential	1	29	1	29	1	29	1	29	1	29
		Total	34	1,000	21	616	18	528	28	823	28	823
The site must be acceptable to the public.	800	Out of sight	10	258	5	129	3	77	9	232	8	206
		Access roads	8	206	6	155	7	181	8	206	7	181
		Isolation from noise, dust, and odor	6	154	3	77	1	26	5	129	4	103
		Surface water pollution potential	4	103	1	26	1	26	3	77	2	52
		Desirability and benefit of site as completed	2	51	1	26	1	26	1	26	1	26
		Desirability of improved land use	1	25	1	26	1	26	1	26	1	26
		Total	31	800	17	439	14	362	27	696	23	594
Impairment of the site ecology must be avoided.	500	Type and density of vegetation	10	416	7	292	5	208	9	375	8	333
		Influence of existing development in the surrounding area on species, variety and density	2	83	1	42	1	42	1	42	1	42
		Total	12	500	8	334	6	250	10	417	9	377
Use of the site must be compatible with the accepted land-use planning in the area.	500	Compatability of completed fill area with future land use plans	10	333	6	200	6	200	9	300	7	233
		Desirability of improving the existing land use	5	166	1	33	1	33	2	67	1	33
		Total	15	500	7	233	7	233	11	367	8	267
The site must be suitable for ready development and operation as a landfill.	300	Life of site	10	136	8	109	9	123	8	109	9	123
		Availability of cover material on site	5	68	1	14	1	14	4	54	1	14
		Ability to divert surface water	5	68	1	14	1	14	4	54	2	27
		General accessibility of site	2	27	1	14	1	14	1	14	1	14
		Total	22	300	12	165	11	151	18	245	13	178
TOTAL SCORE				3,100	65	1,773	56	1,538	94	2,534	81	2,239

examined, it was eliminated from further consideration). Various specialists scored the sites under criteria involving their area of expertise. For example, planners were used to score those criteria related to land use.

The scoring was found to be more effective when all sites were evaluated relative to one criterion before other criteria were examined. Each criterion was given a score ranging from 1 to 10, the higher score represented the desirable direction. Thus, a site with no "potential groundwater pollution hazard", for instance, received a score of 10. The rating was then assigned a pro-rated score. For example, the potential groundwater pollution hazard rating for S-5 was 7; therefore, the pro-rated score = (7/34)x(1,000) = 206

4.4.3 Final Site Selection

Following the scoring system, an economic evaluation of the top sites was performed and documented in Tables 4-7 and 4-8. The total cost was calculated using the following formulas to determine pro-rated cost ($\$/yd^3$) over the life of the site based on the projected sludge volumes.

TABLE 4-7

OPERATING COST ESTIMATES

Description	Site no.			
	S-5	S-10	S-11	S-13
One Full-Time Equipment Operator Cost Includes an Allowance of 30% for Fringe Benefits	$ 15,000	$ 15,000	$ 15,000	$ 15,000
Equipment Operation and Maintenance	15,000	15,000	15,000	15,000
Site Operation and Maintenance	5,000	5,000	3,000	4,000
Leachate Haul Costs	1,000	--	1,000	--
Cover Material Purchase	25,000	--	40,000	--
Temporary Road Surfacing, Access and Highway Cleaning	20,000	15,000	15,000	8,000
Groundwater Monitoring Samples	3,000	2,000	2,000	2,000
Subtotal of Site Costs	$ 84,000	$ 52,000	$ 91,000	$ 44,000
Sludge Hauling Cost	15,000	150,000	25,000	75,000
Total Operating Cost/yr	$99,000	$202,000	$116,000	$119,000
Unit Cost ($\$/yd^3$) based on 18,000 yd^3/yr	$5.50	$11.22	$6.44	$6.61

1 $yd^3 = 0.7646\ m^3$

TABLE 4-8

CAPITAL COST ESTIMATES

	Site no.			
Description	S-5	S-10	S-11	S-13
Land Acquisition				
Number of Acres	20	37	25	30
Cost per Acre	3,300	8,000	2,000	8,300
Purchase Price	66,000	296,000	500,006	249,000
Site Development Costs				
Initial Site Preparation	50,000	30,000	30,000	40,000
Clearing and Grubbing	120,000	2,000	3,000	5,000
Fence and Gate	10,000	12,000	10,000	3,000
Access Roadway (On-Site)	8,000	16,000	3,000	12,000
Leachate Collection System	20,000	--	25,000	--
Storm Water Management	15,000	20,000	15,000	30,000
Reconstruct Primary Access Roadway	--	--	--	100,000
Equipment Storage Shed	15,000	15,000	15,000	15,000
Utilities	2,000	3,000	2,000	3,000
Monitoring	4,000	4,000	4,000	4,000
Subtotal	310,800	398,000	157,000	461,000
Engineering Surveying Subsurface Exploration and Permits (20%)	62,000	79,600	31,400	92,200
Contingency (10%) of Land Acquisition and Site Development Costs	31,000	39,800	15,700	46,100
Equipment				
Backhoe Loader	120,000	80,000	120,000	30,000
Total Capital Cost	415,000	597,400	324,100	674,300
Estimated Site Life (yrs)	10	12	10	12
Unit Cost ($/yd^3) based on 18,000 yd^3/yr	2.30	2.76	1.80	3.12

1 yd^3 = 0.7646 m^3
1 ac = 0.4047 ha

A compilation of data impacting on the final site selection was then assembled in Table 4-9. As shown, the technical prioritization of the sites was S-11, S-13, S-5, and lastly S-10; the cost prioritization was S-5, S-11, S-13, and S-10; and the public acceptance prioritization was S-13, S-5, S-11, and S-10. In this example, Site S-13 was selected on the basis of its (1) top public acceptance ranking, (2) longer life, and (3) completed site use as a needed park. Although S-13 was not the top-ranked site technically, it was determined to be acceptable. Also, the cost of S-13 was relatively high; however, the operating agency was forced to absorb these costs due to the obvious site benefits.

TABLE 4-9

FINAL SITE SELECTION

Map ref.	Site name/ location	Scoring system value	Landfilling method	Proposed final site use	Site life	Total annual cost ($/yd^3)[a]	Public acceptance ranking[b]
S-5	Alton Street Site	1,773	Area fill mound	Open space	10 yrs	7.80	3
S-10	Hunter Road Site	1,538	Wide trench	Return to natural state	12 yrs	13.98	2
S-11	Harringon Blvd. Site	2,534	Area fill mound	Pasture	10 yrs	8.24	4
S-13	Gilford Road Site	2.230	Wide trench	Park	12 yrs	9.73	1

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[a] Sum of capital and operating costs

[b] Provided from attitude survey taken at public meetings. Lower numbers represent less opposition

1 yd^3 = 0.7646 m^3

4.5 References

1. Proposed Classification Criteria for Solid Waste Disposal Facilities. U.S. Environmental Protection Agency. Federal Register. February 6, 1978.

2. Weaver, D.E., C.J. Schmidt, and J.P. Woodyard. Data Base for Standards/Regulations Development for Land Disposal of Flue Gas Cleaning Sludges. U.S. Environmental Protection Agency, Cincinnati, OH. Report No. EPA-600/7-77-118. December 1977. pp. 146-148.

3. Process Design Manual for Land Treatment of Municipal Wastewater. U.S. Environmental Protection Agency. Technology Transfer. Report No. EPA-625/1-77-008. October 1977. pp. C-13-C-19.

4. Brunner, D.R. and Keller, D.J. Sanitary Landfill Design and Operation. U.S. Environmental Protection Agency. Washington, DC. Report No. SW65ts. 1972. pp. 17.

5. Sexsmith, D.P. et al. Selection Criteria, Methods, and Scoring System for Sanitary Landfill Site Selection. In: Proceedings of Canadian Conference on Solid Waste. 1976. pp. 301-317.

CHAPTER 5

DESIGN

5.1 Purpose and Scope

The objective of a sludge landfill design is to direct and guide the construction and on-going operation of the landfill. A design should ensure (1) compliance with pertinent regulatory requirements, (2) adequate protection of the environment, and (3) cost-efficient utilization of site manpower, equipment, storage volume, and soil. A design package (consisting of all design documents) should be prepared to provide a record of the landfill design. These may consist of drawings, specifications, and reports.

The purpose of this chapter is to provide guidance on the design of a sludge landfill. Specific topics addressed include:

1. Typical permitting procedures and regulatory requirements (Section 5.2)
2. Design methodology (Section 5.3)
3. Relevant data and sources of information (Section 5.3)
4. Contents of the design package (Section 5.3)
5. Information on specific landfilling method designs (Sections 5.4 through 5.6)
6. Information on other designs (Sections 5.7 through 5.16)

5.2 Regulations and Permits

Many regulatory and approving agencies require permits before a sludge landfill can be constructed or operated. The sludge landfill design is generally an integral part of the application for such permits. Accordingly, all pertinent agencies should be contacted early in the design phase to (1) identify regulations impacting on the prospective sludge landfill, (2) determine the extent, detail, and format of the application, and (3) obtain any permit application forms. Once this information has been collected, the design can proceed in a more efficient manner toward the goal of receiving the necessary permits.

Requirements and permits relevant to sludge landfills are found to exist on the State, and local levels. One program of concern is the EPA Construction Grants Program administered by the Office of Water Program Operations. Grants can be received from this source to cover up to 75% of the capital costs (including land acquisition, equipment purchase, and site preparation) for the entire sludge management system. Since this system includes both in-plant sludge treatment facilities as well as disposal facilities, the application must address the sludge landfill operation as well. Accordingly, it is important to proceed with a landfill design which is in accordance with EPA grant requirements if grants are desired. Other Federal requirements relevant to sludge landfills are contained in the Criteria for the Classification of Solid Waste Disposal Facilities [1]. These Criteria address the following topic areas:

1. Environmentally sensitive areas
2. Surface water
3. Groundwater
4. Air
5. Application on land used for the production of food chain crops
6. Disease vectors
7. Safety

Environmentally sensitive areas are more specifically identified as (1) wetlands, (2) flood plains, (3) permafrost areas, (4) critical habitats of endangered species, and (5) recharge zones for sole source aquifers. As stated in the Criteria, disposal facilities should not be located in environmentally sensitive areas when feasible alternatives exist, unless it can be clearly demonstrated that there will be no significant impact on the ecosystem or human health from the operation of a facility in such an area [1].

Safety concerns are more specifically identified as (1) explosive gases, (2) toxic or asphyxiating gases, (3) fires, (4) bird hazards to aircraft, and (5) access. As stated in the Criteria, disposal facilities should not pose a safety hazard to facility employees, users, or the public with respect to any of the above features. Requirements also exist in each of the remaining topic areas and the Criteria should be consulted for a complete description. Many of the requirements in the Criteria are already addressed in State regulations. Table 5-1 provides an analysis of the Criteria topic areas included in State regulations.

Several permits relevant to sludge landfills are identified and mandated by these Criteria. Generally these include:

1. NPDES permit required for location of a sludge landfill in wetlands. It is also required for any point source discharges at sludge landfills.

2. Army Corps of Engineers permit required for the construction of any levee, dike, or other type of containment structure to be placed in the water at a sludge landfill located in wetlands.

3. Office of Endangered Species permit may be required from the Fish and Wildlife Service, Department of the Interior for location of a sludge landfill in critical habitats of endangered species.

State and local regulations and permits are highly variable from jurisdiction to jurisdiction. Depending on the jurisdiction, one or more permits may be required for a sludge landfill. Typical permits on the State and local levels include:

1. Solid waste management permit
2. Special use permit
3. Zone change certification for a change to a zoning appropriate for a sludge landfill
4. Sedimentation control permit for surface runoff into water courses
5. Highway department permit for entrances on public roads and increased traffic volumes
6. Construction permit for landfill site preparation
7. Operation permit for on-going landfill operation
8. Mining permit for excavations
9. Fugitive dust permit
10. Business permit for charging fees
11. Closure permit
12. Building permit to construct buildings on the landfill site

Depending on local procedures, permits may be required from both state and local regulatory agencies. State regulatory agencies which require such submittals may include:

1. Solid waste management agencies
2. Water quality control agencies
3. Health departments
4. Building departments

TABLE 5-1

ANALYSIS OF FEDERAL CRITERIA VS. STATE REGULATIONS [2]

State	Environmentally Sensitive Areas					Surface Water	Groundwater	Air	Disease Vectors	Safety					% of Total[a]
	Wetlands	Flood Plains	Permafrost	Critical Habitats	Sole-Source Aquifers					Explosive Gases	Fires	Toxic Gases	Bird Hazards	Access	
Alabama						X	X	X	X						
Alaska			X			X	X	X	X		X				50%
Arizona						X	X	X	X					X	60%
Arkansas		X				X	X	X	X		X				50%
California	X	X		X		X	X	X	X		X			X	70%
Colorado		X				X		X	X	X	X	X	X	X	100%
Connecticut		X				X			X		X			X	60%
Delaware	X					X	X		X	X	X	X		X	70%
Florida		X			X	X	X	X	X	X				X	60%
Georgia	X					X	X	X	X	X	X	X	X	X	100%
Hawaii		X				X			X		X			X	70%
Idaho						X	X	X	X		X				40%
Illinois						X	X	X	X		X			X	60%
Indiana					X	X		X	X		X			X	60%
Iowa		X			X	X		X	X	X	X	X		X	80%
Kansas								X	X		X			X	60%
Kentucky		X				X	X	X	X		X			X	40%
Louisiana							X		X		X			X	70%
Maine	X					X			X						20%
Maryland	X	X				X	X	X	X		X			X	50%
Massachusetts	X	X				X		X	X	X	X	X		X	90%
Michigan					X	X	X	X	X		X			X	60%
Minnesota	X	X				X	X	X	X		X			X	70%
Mississippi		X						X	X	X	X	X	X	X	100%
Missouri		X				X	X	X	X		X			X	50%
Montana		X				X	X	X	X	X	X	X		X	90%
Nebraska		X				X	X	X	X					X	60%
Nevada						X	X	X	X		X			X	70%
New Hamsphire	X	X				X	X	X	X		X			X	60%
New Jersey	X					X	X	X	X	X	X	X		X	90%
New Mexico						X	X		X	X	X	X	X		90%
New York						X	X	X	X		X			X	50%
North Carolina		X				X	X	X	X					X	50%
North Dakota						X			X		X			X	70%
Ohio						X	X		X					X	30%
Oklahoma						X		X	X		X			X	50%
Oregon		X				X	X	X	X		X			X	50%
Pennsylvania		X				X	X	X	X		X			X	70%
Rhode Island						X	X	X	X		X			X	70%
South Carolina						X	X	X	X	X	X	X		X	80%
South Dakota		X				X	X	X	X					X	50%
Tennessee		X				X	X	X	X		X			X	70%
Texas		X				X	X	X	X		X			X	70%
Utah						X		X	X	X	X	X	X	X	100%
Vermont						X		X	X		X				40%
Virginia						X	X	X	X					X	40%
Washington	X	X				X	X	X	X		X				50%
West Virginia						X	X	X	X	X	X	X		X	90%
Wisconsin	X					X	X	X	X		X			X	40%
Wyoming						X	X	X	X		X			X	90%
															60%
Total	11/50	23/50	1/50	1/50	4/50	47/50	37/50	42/50	50/50	14/50	41/50	13/50	5/50	42/50	
% of Total	22%	45%	2%	2%	8%	94%	74%	84%	100%	28%	82%	26%	10%	84%	

[a] Environmentally sensitive areas counted as one criterion for row totals.

Local regulatory agencies may include:

1. Health departments
2. Planning and/or zoning commissions
3. Board of county commissioners

In many jurisdictions more than one of the State or local agencies has authority over a disposal site. Also, in some jurisdictions, one agency has control over sludge-only landfills while another agency has control over refuse landfills.

The reviewing agency may require the submittal of information on standard forms or in a prescribed format in order to facilitate the review process. In any event, applicants are responsible for the completeness and accuracy of the application package. The completed application package is then reviewed by the regulatory agency. The time of the review period will vary depending upon the regulatory agency, their attention to detail, the number of applications preceding it, etc. From experience, this process has been found to take at least one month and usually 6 to 12 months or longer. After a permit is issued, it can be valid for various durations, depending largely upon the submittal of inspection/ performance reports and the outcome of on-site inspections.

5.3 Design Methodology and Data Compilation

Adherence to a carefully planned sequence of activities to develop a sludge landfill design minimizes project delays and expenditures. A checklist of design activities is presented in Table 5-2. These activities are listed somewhat in their order of performance. However, in many cases separate tasks can and should be performed concurrently or even out of the order shown.

As shown in Table 5-2, initial tasks consist of compiling existing information and generating new information on sludge and site conditions. Obviously, some of this information would have already been collected in the site selection phase. Generally however, additional and more detailed information will have to be collected in the design phase.

Information utilized during both the site selection and design phases can be derived either from existing sources or new sources (i.e., field investigation). A listing of possible existing information sources has been included as Table 5-3. A listing of possible new information sources has been included in Table 5-4.

TABLE 5-2

SLUDGE LANDFILL DESIGN CHECKLIST

Step	Task
1	Determine sludge volumes and characteristics
	a. Existing
	b. Projected
2	Compile existing and generate new site information.
	a. Perform boundary and topographic survey
	b. Prepare base map of existing conditions on-site and near-site
	(1) Property boundaries
	(2) Topography and slopes
	(3) Surface water
	(4) Utilities
	(5) Roads
	(6) Structures
	(7) Land use
	c. Compile hydrogeological information and prepare location map
	(1) Soils (depth, texture, structure, bulk density, porosity, permeability, moisture, ease of excavation, stability, pH, and cation exchange capacity)
	(2) Bedrock (depth, type, presence of fractures, location of surface outcrops)
	(3) Groundwater (average depth, seasonal fluctuations, hydraulic gradient and direction of flow, rate of flow, quality, uses)
	d. Compile climatological data
	(1) Precipitation
	(2) Evaporation
	(3) Temperature
	(4) No. of freezing days
	(5) Wind direction
	e. Identify regulations (Federal, State, and local) and design standards
	(1) Requirements for sludge stabilization
	(2) Sludge loading rates
	(3) Frequency of cover
	(4) Distances to residences, roads, and surface water
	(5) Monitoring
	(6) Roads
	(7) Building codes
	(8) Contents of application for permit
3	Design filling area
	a. Select landfilling method based on:
	(1) Sludge characteristics
	(2) Site topography and slopes
	(3) Site soils
	(4) Site bedrock
	(5) Site groundwater
	b. Specify design dimensions
	(1) Trench width
	(2) Trench depth
	(3) Trench length
	(4) Trench spacing
	(5) Sludge fill depth
	(6) Interim cover soil thickness
	(7) Final cover soil thickness

TABLE 5-2 (Continued)

c. Specify operational features

(1) Use of bulking agent
(2) Type of bulking agent
(3) Bulking ratio
(4) Use of cover soil
(5) Method of cover application
(6) Need for imported soil
(7) Equipment requirements
(8) Personnel requirements

d. Compute sludge and soil uses

(1) Sludge application rate
(2) Soil requirements

4 Design facilities

a. Leachate controls
b. Gas controls
c. Surface water controls
d. Access roads
e. Special working areas
f. Structures
g. Utilities
h. Fencing
i. Lighting
j. Washracks
k. Monitoring wells
l. Landscaping

5 Prepare design package

a. Develop preliminary location plan of fill areas
b. Develop landfill contour plans

(1) Excavation plans
(2) Completed fill plans

c. Compute sludge storage volume, soil requirement volumes, and site life
d. Develop final location plan showing:

(1) Normal fill areas
(2) Special working areas
(3) Leachate controls
(4) Gas controls
(5) Surface water controls
(6) Access roads
(7) Structures
(8) Utilities
(9) Fencing
(10) Lighting
(11) Washracks
(12) Monitoring wells
(13) Landscaping

e. Prepare elevation plans with cross-sections of:

(1) Excavated fill
(2) Completed fill
(3) Phased development of fill at interim points

f. Prepare construction details

(1) Leachate controls
(2) Gas controls
(3) Surface water controls
(4) Access roads
(5) Structures
(6) Monitoring wells

g. Prepare cost estimate
h. Prepare design report
i. Submit application and obtain required permits
j. Prepare operator's manual

TABLE 5-3

SOURCES OF EXISTING INFORMATION

General Information	Specific Information	Source
Base Map	General	• County road department • City, county, or regional planning department • U.S. Geological Survey (USGS) office or outlets for USGS map sales (such as engineering supply stores and sporting goods stores) • U.S. Department of Agriculture (USDA), Agricultural Stabilization and Conservation Service (ASCS) • Local office of USGS • County Department of Agriculture, Soil Conservation Service (SCS) • Surveyors and aerial photographers in the area
	Topography and Slopes	• USGS topographic maps • USDA, ARS, SCS aerial photos
	Land Use	• City, county, or regional planning agency
	Vegetation	• County agricultural department • Agriculture department at local university
Soils	General	• USDA, Soil Conservation Service (SCS), District Managers, Local Extension Service • USGS reports • Geology or Agriculture Department of local university
Bedrock	General	• USGS reports • State Geological Survey reports • Professional geologists in the area • Geology Department of local university
Groundwater	General	• Water Supply Department • USGS water supply papers • State or regional water quality agencies • USDA, SCS • State or Federal water resources agencies • Local health department
Climatology	General	• National Oceanic and Atmospheric Administration (NOAA) • Nearby airports

TABLE 5-4

FIELD INVESTIGATIONS FOR NEW INFORMATION

General Information	Specific Information	Method and Equipment
Base Map	Property boundaries	Field survey via transit
	Topography and slopes	Field survey via alidade
	Surface water	Field survey via alidade
	Utilities	Field survey via alidade
	Roads	Field survey via alidade
	Structures	Field survey via alidade
	Land use	Field survey via alidade
	Vegetation	Field survey via alidade
Soils	Depth	Soil boring and compilation of boring log
	Texture	Soil sampling and testing via sedimentation methods (e.g., sieves)
	Structure	Soil sampling and inspection
	Bulk density	Soil sampling and testing via gravimetric, gamma ray detection
	Porosity	Calculation using volume of voids and total volume
	Permeability	Soil sampling and testing via piezometers and lysimeters
	Moisture	Soil sampling and testing via oven drying
	Ease of excavation	Test excavation with heavy equipment
	Stability	Test excavation of trench and loading of sidewall or Hueem stabilometer
	pH	Soil sampling and testing via pH meter
	Cation exchange capacity	Soil sampling and testing
Bedrock	Depth	Boring and compilation of boring log
	Type	Sampling and inspection
	Fractures	Field survey via alidade or Brunton
	Surface outcrops	Field survey via alidade or Brunton
Groundwater	Depth	Well installation and initial readings
	Seasonal fluctuations	Well installation and year-round readings
	Hydraulic gradient	Multiple well installation and comparison of readings
	Rate of flow	Calculation based on permeability and hydraulic gradient
	Quality	Groundwater sampling and testing
	Uses	Field survey via inspection
Climatology	Precipitation	Rain gauge
	Evaporation	Class A Evaporation Pan
	Temperature	Standard thermometer
	No. of freezing days	Minimum-maximum temperature thermometer
	Wind direction	Wind arrow

Before proceeding to the final design it is advisable to recontact regulatory agencies who were contacted during the site selection process and others to try to determine all of their requirements and procedures for permit application submittals. This will also provide an opportunity to discuss design concepts, get questions answered, and determine any special or new requirements. Maintenance of close liaison with State and local regulatory officials throughout the design effort is normally helpful in securing a permit without excessive redesigns.

A complete design package may include plans, specifications, a design report, cost estimate, and operator's manual. Generally, the cost estimate and operator's manual are prepared strictly for in-house uses, while plans, specifications, and design reports are submitted to regulatory agencies in the permit application. Plans and specifications typically include:

1. Base map showing existing site conditions. The map should be of sufficient detail, with contour intervals of no more than 5 ft (1.5 m) and a scale not to exceed 1 in. = 200 ft (1 cm = 24 m).

2. Site preparation plan locating sludge fill and soil stockpile areas as well as site facilities. A small-scale version of a site preparation plan has been included as Figure 5-1.

3. Development plan showing initial excavated and final completed contours in sludge filling areas.

4. Elevations showing cross-sections to illustrate phased development of sludge landfill at several interim points.

5. Construction details illustrating detailed construction of site facilities.

6. Completed site plan including final site landscaping, appurtenances, and other improvements.

A design report typically includes:

1. Site description including existing site size, topography and slopes, surface water, utilities, roads, structures, land use, soils, groundwater, bedrock, and climatology.

2. Design criteria including sludge types and volumes and fill area design dimensions.

3. Operational procedures including site preparation, sludge unloading, sludge handling, and sludge covering as well as equipment and personnel requirements.

4. Environmental safeguards including control of leachate, surface water, gas, odor, flies, etc.

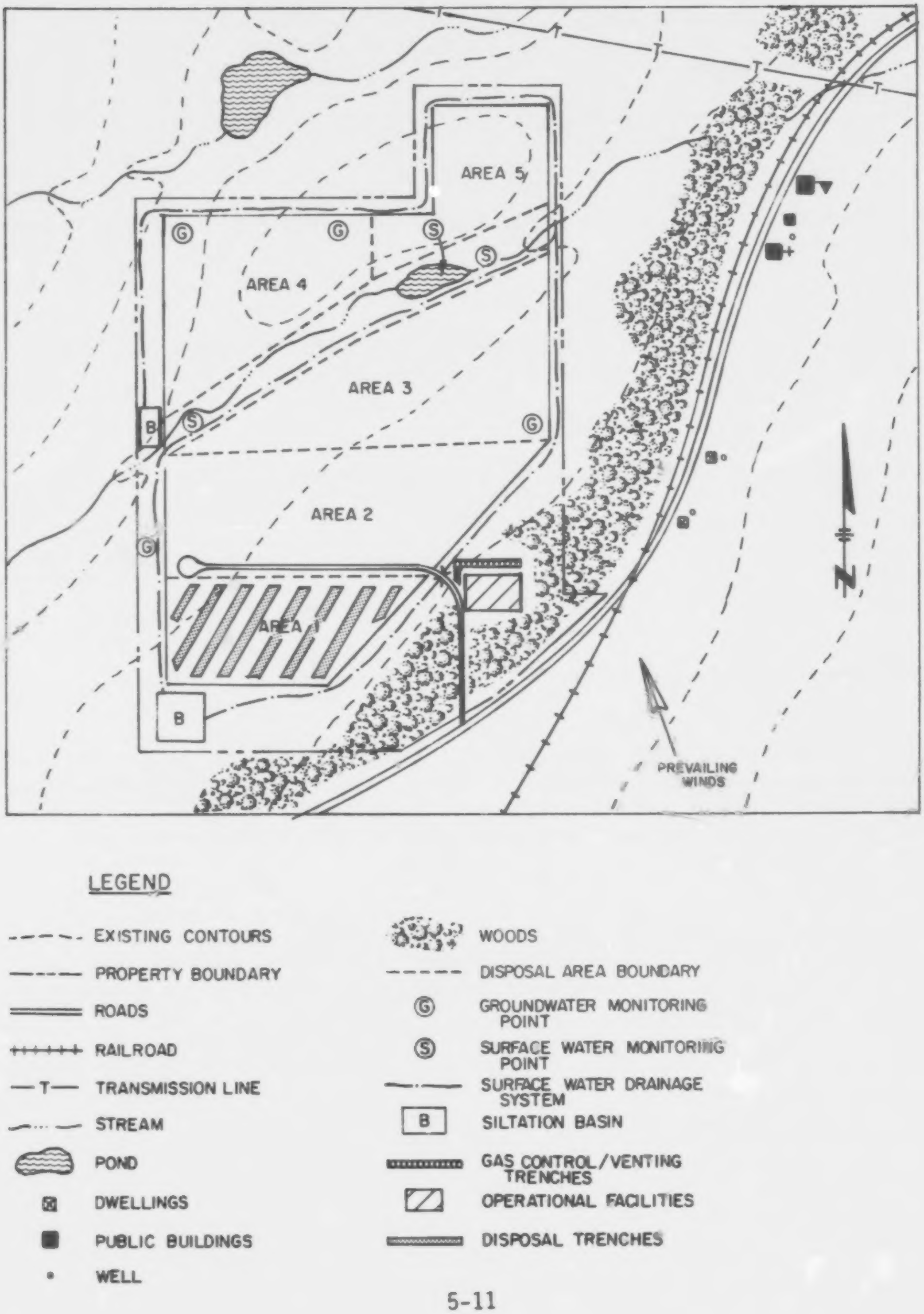
5.4 Selection of Landfilling Method

Several alternative methods and sub-methods for sludge landfilling were identified and described in Chapter 3, Sludge Characteristics and Landfilling Methods. These include:

1. Sludge-only trench
    - a. narrow trench
    - b. wide trench

FIGURE 5-1

TYPICAL SITE PREPARATION PLAN



2. Sludge-only area fill
    a. area fill mound
    b. area fill layer
    c. diked containment
3. Codisposal
    a. sludge/refuse mixture
    b. sludge/soil mixture

As shown in Table 3-7, the most significant features affecting method selection are:

1. Sludge percent solids
2. Sludge characteristics (stabilized or unstabilized)
3. Hydrogeology (deep or shallow groundwater and bedrock)
4. Ground slopes

Having chosen a site (Chapter 4) and a landfilling method (Chapter 3) appropriate to that site, a suitable design must be established. Sections 5.5, 5.6, and 5.7 discuss considerations that are relevant to trench, area fill, and codisposal landfills respectively. In addition, Chapter 10, Design Examples, provides an illustration of how a landfilling method is selected for a given site.

5.5 Sludge-Only Trench Designs

In a sludge-only trench operation, sludge is placed entirely below the original ground surface. Sludge is usually dumped directly into trenches from haul vehicles. On-site equipment is used only to excavate trenches and apply cover; equipment does not usually come into contact with the sludge.

Sludge-only trenches have been further classified into narrow trenches and wide trenches. If one of these landfilling methods has been selected, design of the filling area consists primarily of determining the following parameters:

1. Excavation depth
2. Spacing
3. Width
4. Length
5. Orientation
6. Sludge fill depth
7. Cover thickness

A methodology for determining these parameters is included below in Table 5-5.

TABLE 5-5

DESIGN CONSIDERATIONS FOR SLUDGE-ONLY TRENCHES

Design Parameter	Determining Factor	Consideration	
Excavation Depth	Depth to groundwater Depth to bedrock Soil permeability Cation exchange capacity of soil	Sufficient thickness of soil must be maintained between trench bottom and groundwater or bedrock. Required minimum separation varies from 2 to 5 ft. Larger separations may be required for higher than normal soil permeabilities or sludge loading rates.	
	Equipment limitations	Normal excavating equipment can excavate efficiently to depths of 10 ft. Depths from 10 to 20 ft are less efficient operations for normal equipment; larger equipment may be required. Depths over 20 ft are not usually possible.	
	Sidewall stability	Sidewall stability determines maximum depth of trench. If haul vehicles are to dump sludge into trench from above, straight sidewall should be employed. Tests should be performed at site with a loaded haul vehicle to ensure that sidewall height as designed will not collapse under operating conditions.	
Spacing	Sidewall stability	Trench spacing is determined by sidewall stability. Greater trench spacing will be required when additional sidewall stability is required. As a general rule, 1.0 to 1.5 ft of spacing should be allowed between trenches for every 1 ft of trench depth.	
	Soil stockpiles Vehicle access	Sufficient space should be maintained between trenches for placement of trench spoil stockpiled for cover as well as to allow access and free movement by haul vehicles and operating equipment.	
Width	Sludge solids content	Widths of 2 to 3 ft for typical sludge with solids content from 15 to 20%. Widths of more than 3 ft for typical sludge with solids content more than 20%. Certain sludge (e.g., polymer treated) may require higher solids contents before these widths can apply.	
	Equipment limitations	Widths up to 10 ft for typical equipment (such as front end loader) based on solid ground alongside trench. Widths up to 40 ft for some equipment (such as a dragline) based on solid ground. Unlimited widths for cover applied by equipment (such as bulldozers) which proceed out over sludge.	
	Equipment efficiencies	Equipment	Typical Widths
		Trenching machine	2 ft
		Backhoe	2-6 ft
		Excavator	4-22 ft
		Track dozer	≥10 ft
		Track loader	≥10 ft
		Dragline	≥40 ft
		Scraper	≥20 ft
Length	Sludge solids content Ground slopes	If sludge solids are low and/or trench bottoms not level, trench should be discontinued or dikes placed inside trench to contain sludge in one area and prevent it from flowing over large area.	
Orientation	Land availability	Trenches should be parallel to optimize land utilization.	
	Ground slopes	For low solids sludge, axis of each trench should be parallel to topographic contours to maintain constant bottom elevation within each trench and prevent sludge from flowing. With higher solids sludge, this requirement is not necessary.	

TABLE 5-5 (Continued)

Design Parameter	Determining Factor	Consideration		
Sludge fill depth	Trench width Cover application method	Trench width	Cover application method	Minimum distance from top
		2-3 ft	Land-based equipment	1-2 ft
		> 3 ft	Land-based equipment	3 ft
		≥10 ft	Sludge-based equipment	4 ft
Cover thickness	Trench width Cover application method	Trench width	Cover application method	Cover thickness
		2-3 ft	Land-based equipment	2-3 ft
		> 3 ft	Land-based equipment	3-4 ft
		≥10 ft	Sludge-based equipment	4-5 ft

1 ft = 0.305 m

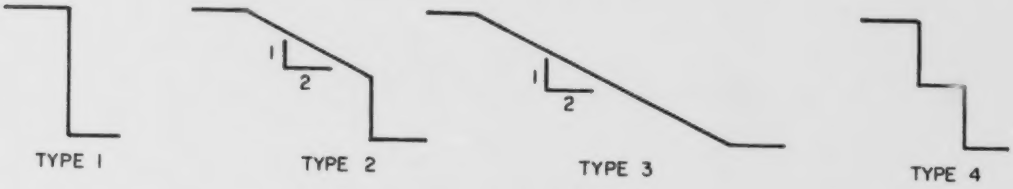
Trench spacing is perhaps the most important and yet most difficult design parameter to determine. Trench spacing is defined as the width of solid undisturbed ground which is maintained between adjacent trenches. Generally, trench spacing should be as small as possible to optimize land utilization rates. However, the trench spacing must be sufficient to resist sidewall cave-in. Failure of the trench sidewalls is a safety hazard and reduces the volume of the trench available for disposal. Factors to consider in determining trench spacing include: (1) the weight of the excavating machinery, (2) the bearing capacity of the soil (which is a factor of soil cohesion, density, and compaction), (3) saturation level of the soil (which may be significantly influenced by the moisture content of the sludge deposited), (4) the depth of the trench, and (5) soil stockpiling and cover placement procedure.

A test which is used primarily to determine the adequacy of soils in highway construction provides general guidance in determining trench configurations (spacing and depth). This test determines the stability of a soil by means of the Hveem stabilometer, which measures the transmitted horizontal pressure due to a vertical load. The stability, expressed as the resistance value (R), represents the shear resistance to plastic deformation of a saturated soil at a given density [3]. This test is described under AASHO T175 (American Association of State Highway Officials).

A general rule of thumb to follow in establishing trench spacing is that for every 1 ft (0.3 m) of trench depth, there should be 1 to 1.5 ft (0.3 to 0.5 m) of space between trenches. If large inter-trench spaces are not practical, the problem of sidewall instability may be relieved by utilizing one of the four trench sidewall variations shown in Figure 5-2. In any event, test cell trenches should be used to determine the operational feasibility of any trench design. Such tests should be

FIGURE 5-2

TRENCH SIDEWALL VARIATIONS



performed by excavating adjacent trenches to the specified depth, width, and spacing. A haul vehicle fully loaded with sludge should then back up to the trench to determine if the sidewall stability is sufficient.

Using the considerations included in Table 5-5, design parameters can be determined for a variety of sludge and site conditions. These considerations have been employed to develop some alternative design scenarios for trenches shown in Table 5-6. In some cases, sludge and site conditions may indicate that it is wholly appropriate to utilize all of the design parameters shown in one of these trench scenarios for application to a real world situation. However, because of the great variety of sludge and site conditions and their combinations, some adaptation of one of these scenarios will be necessary in most cases. In any event, design parameters should not be merely extracted from these tables; parameters should always be well-considered and tested before full-scale application. An example of a trench design (which utilizes these tables initially, followed by engineering investigation and field testing) has been included in Chapter 10, Design Examples.

5.5.1 Narrow Trench

Narrow trenches have widths less than 10 ft (3.0 m) and usually receive low solids sludge with solids contents as low as 15%. Excavation and cover application in narrow trench operations is via equipment based on solid ground alongside the trench. Illustrations of typical narrow trench operations are included as Figures 5-3 and 5-4.

The method of sludge placement in a narrow trench is dependent upon the type of haul vehicle and upon trench sidewall stability. Usually trench sidewalls are sufficiently stable and sludge may be dumped from the haul

TABLE 5-6

ALTERNATIVE DESIGN SCENARIOS

Identification			Site Preparation				Sludge Bulking			Sludge Filling			Sludge Covering				Miscellaneous	
Scenario No.	Landfilling method	Sludge Solids Content (%)	Width (ft)	Depth (ft)	Length (ft)	Spacing (ft)	Bulking Performed	Bulking agent	Bulking ratio (agent: sludge)[a]	Sludge depth per lift (ft)	No. lifts	Sludge application rate (yd^3/acre)	Cover applied	Location of equipment	Cover Thickness Interim (ft)	Cover Thickness Final (ft)	Imported soil required	Primary equipment
1	Narrow trench	15	2	3	1,000	3	no	—	—	2	1	1,290	yes	Land-based	—	3	no	Trenching machine
2	Narrow trench	17	2	8	1,000	8	no	—	—	6	1	1,940	yes	Land-based	—	3	no	Backhoe
3	Narrow trench	25	6	10	100	12	no	—	—	7	1	3,750	yes	Land-based	—	4	no	Backhoe with loader
4	Narrow trench	28	8	8	100	12	no	—	—	5	1	3,230	yes	Land-based	—	4	no	Excavator
5	Wide trench	26	40	7	400	20	no	—	—	4	1	4,100	yes	Land-based	—	4	no	Dragline
6	Wide trench	32	60	8	600	30	no	—	—	4	1	4,100	yes	Sludge-based	—	5	no	Track dozer
7	Area fill mound	20	—	—	—	—	yes	soil	2:1	6	1	3,230	yes	Sludge-based	—	3	yes	Track loader
8	Area fill mound	35	—	—	—	—	yes	soil	0.5:1	6	2	12,910	yes	Sludge-based	3 ft	5	yes	Track loader, backhoe
9	Area fill layer	15	—	—	—	—	yes	soil	1:1	1	3	2,420	yes	Sludge-based	0.5	2	yes	Track dozer
10	Area fill layer	30	—	—	—	—	yes	soil	0.25:1	3	2	7,740	yes	Sludge-based	1	2	yes	Track dozer, grader
11	Diked containment	25	50	30	100	30	yes	soil	0.5:1	6	4	12,410	yes	Land-based	1	3	no	Dragline
12	Diked containment	32	100	23	200	50	no	—	--	8	2	13,770	yes	Sludge-based	3	4	no	Track dozer
13	Sludge/refuse mixture	3	—	—	—	—	yes	refuse	7 tons:1 wet ton	6	3	2,520	yes	Sludge-based	0.5	2	yes	Track dozer
14	Sludge/refuse mixture	28	—	—	—	—	yes	refuse	4 tons:1 wet ton	6	3	4,140	yes	Sludge-based	0.5	2	yes	Track dozer
15	Sludge/soil mixture	20	—	—	—	—	yes	soil	1:1	1.0	1	1,600	no	—	—	—	no	Tractor with disc

[a] Volume basis unless otherwise noted.

1 ft = 0.305 m
1 ton = 0.907 Mg
1 yd^3 = 0.765 m^3
1 acre = 0.405 ha

FIGURE 5-3

CROSS-SECTION OF TYPICAL NARROW TRENCH OPERATION

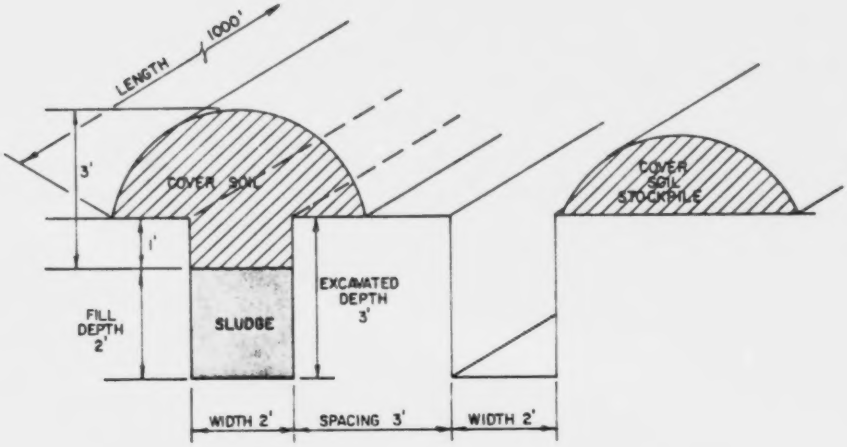
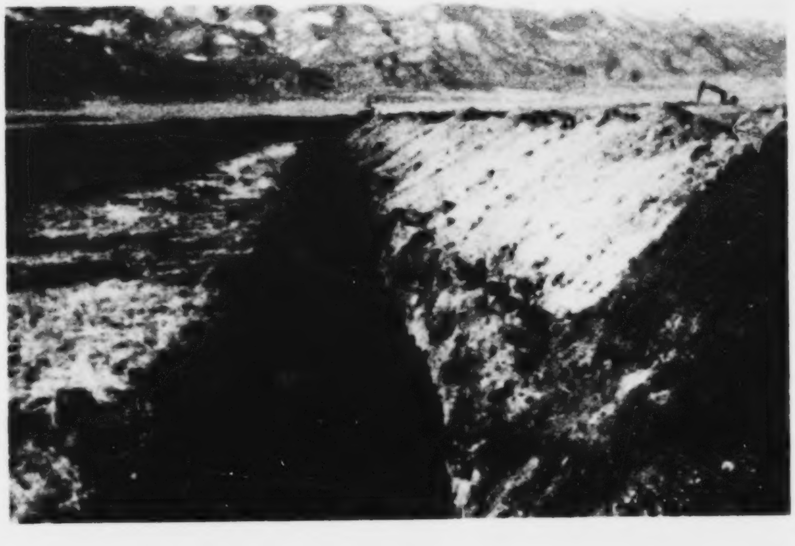


FIGURE 5-4

NARROW TRENCH OPERATION



vehicle directly into trenches. However, if sidewalls are not sufficiently stable, the sludge may be delivered to the trench in a chute-extension similar to that found on concrete trucks or pumped in via portable pumps. In some cases (particularly in wet weather) it may be necessary to dump the sludge on solid ground near the trench and have on-site equipment push the sludge into the trench.

5.5.2 Wide Trench

Wide trenches have widths greater than 10 ft (3.0 m) and usually receive higher solids sludge with solids contents of 20% and more. Excavation of wide trenches is usually via equipment which enters the trench itself. Cover application may be by equipment based on solid ground alongside the trench, but is usually accomplished by equipment that proceeds out over the sludge spreading a layer of cover soil before it. Illustrations of typical wide trench operations are included as Figures 5-5 and 5-6.

FIGURE 5-5

WIDE TRENCH OPERATION

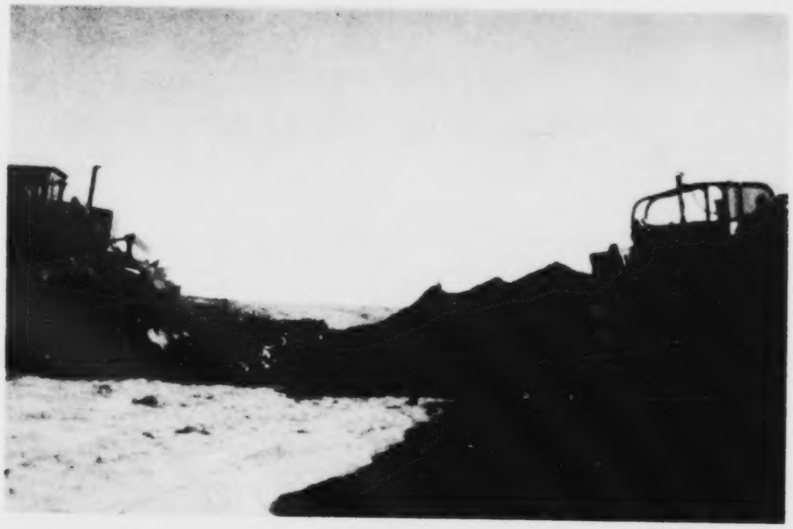
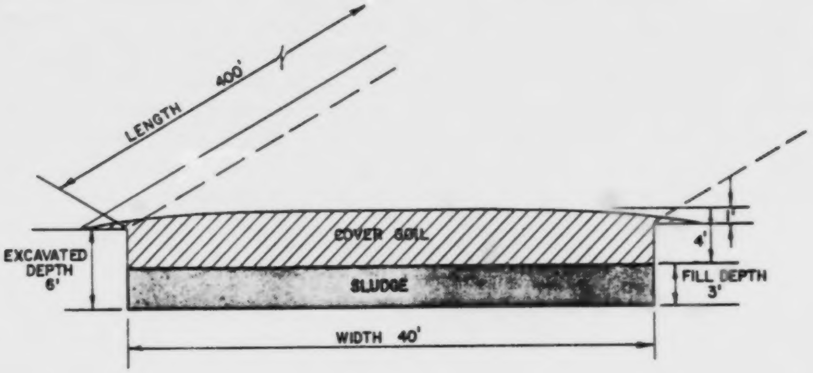


FIGURE 5-6

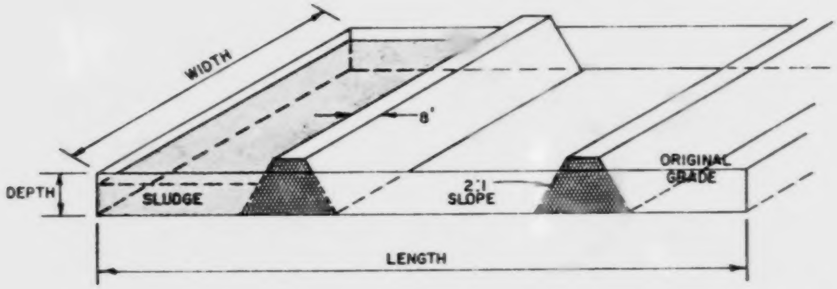
CROSS-SECTION OF TYPICAL WIDE TRENCH OPERATION



The method of sludge placement in wide trenches may be either (1) from haul vehicles directly entering the trench and dumping sludge in 3 to 4 ft (0.9 to 1.2 m) high piles or (2) from haul vehicles parked at the top of trench sidewalls and dumping sludge into the trench. For the first of these two cases sludge should have a solids content of 32% or more to ensure that the sludge will not slump and can be maintained in piles. For the second of these cases, sludge should have a solids content less than 32% to ensure that it will flow evenly throughout the trench and not accumulate at the dumping location. Of course, when sludge is free-flowing, some means will be needed to confine the sludge to specific areas in a continuous trench. Dikes are often used for this purpose as illustrated in Figure 5-7.

FIGURE 5-7

CROSS-SECTION OF WIDE TRENCH WITH DIKES



5.6 Sludge-Only Area Fill Design

In a sludge-only area fill operation, sludge is usually placed entirely above the original ground surface. The sludge as received is usually mixed with soil to increase its effective solids content and stability. Several consecutive lifts of this sludge/soil mixture are usually then applied to the filling area. Soil may be applied for interim cover in addition to its usual application for final cover. On-site equipment usually does come into contact with the sludge while performing functions of mixing the sludge with soil; transporting this mixture to the fill area; mounding or layering this mixture; and spreading cover over the mixture.

Sludge-only area fills have been further classified into area fill mounds, area fill layers, and diked containments. If one of these landfilling methods has been selected, design of the filling area may consist primarily of determining the following parameters:

1. Bulking ratio
2. Cover application procedure
3. Width (of diked containment)
4. Depth of each lift
5. Interim cover thickness
6. Number of lifts
7. Depth of total fill (of diked containment before final cover)
8. Final cover thickness

A methodology for determining these factors is included below in Table 5-7.

TABLE 5-7

DESIGN CONSIDERATIONS FOR SLUDGE-ONLY AREA FILLS

Design Parameter	Consideration		
	Method	Solids Content	Bulking Ratio
Bulking ratio	Area fill mound	20-28%	2 soil:1 sludge
		28-32%	1 soil:1 sludge
		≥ 32%	0.5 soil:1 sludge
	Area fill layer	15-20%	1 soil:1 sludge
		20-28%	0.5 soil:1 sludge
		28-32%	0.25 soil:1 sludge
		≥ 32%	Not required
	Diked containment	[illegible]	0.5 soil:1 sludge
		28-32%	0.25 soil:1 sludge
		≥ 32%	Not required
	Method	Solids Content	Cover Application Procedure
Cover application procedure	Area fill mound	≥ 20%	Sludge-based equipment
	Area fill layer	≥ 15%	Sludge-based equipment
	Diked containment	20-28%	Land-based equipment
		≥ 28%	Sludge-based equipment

TABLE 5-7 (Continued)

Design Parameter	Consideration		
	Cover Application Procedure	Equipment Used	Width
Width (of diked containment)	Land-based equipment	Dragline	≤ 40 ft
	Sludge-based equipment	Track dozer	Not limited
	Method	Sludge Solids	Lift Depth
Depth of each lift	Area fill mound	> 20%	6 ft
	Area fill layer	15-20%	1 ft
		≥ 20%	2-3 ft
	Diked containment	20-28%	4-6 ft
		≥ 28%	6-10 ft
	Method	Cover Application Procedure	Interim Cover Thickness
Interim cover thickness	Area fill mound	Sludge-based equipment	3 ft
	Area fill layer	Sludge-based equipment	0.5-1 ft
	Diked containment	Land-based equipment	1-2 ft
		Sludge-based equipment	2-3 ft
	Method	Sludge Solids Content	No. of Lifts
Number of lifts	Area fill mound	20-28%	1 maximum
		≥ 28%	3 maximum
	Area fill layer	≥ 15%	1-3 typical
	Diked containment	≥ 20%	1-3 typical
	Cover Application Procedure	Depth of Total Fill	
Depth of total fill (of diked containment before final cover)	Land-based equipment	No higher than 3 ft below top of dikes	
	Sludge-based equipment	No higher than 4 ft below top of dikes	
	Method	Cover Application Procedure	Final Cover Thickness
Final cover thickness	Area fill mound	Sludge-based equipment	1 ft
	Area fill layer	Sludge-based equipment	1 ft
	Diked containment	Land-based equipment	3-4 ft
		Sludge-based equipment	4-5 ft

1 ft = 0.305 ft

Using the considerations included in Table 5-7, the design parameters can be determined for a variety of sludge and site conditions. These considerations have been employed to develop some alternative design scenarios for area fills which were included earlier in Table 5-6. An example of an area fill design (which utilizes these tables initially, followed by investigation and testing) has been included in Chapter 10, Design Examples.

5.6.1 Area Fill Mound

At area fill mound operations, sludge/soil mixtures are stacked into mounds approximately 6 ft (1.8 m) high. Cover soil is applied atop each lift of mounds in a 3 ft (0.9 m) thickness. The cover thickness may be increased to 5 ft (1.5 m) if additional mounds are applied atop the first lift. Illustrations of typical mound operations are included as Figures 5-8 and 5-9.

FIGURE 5-8

CROSS-SECTION OF TYPICAL AREA FILL MOUND OPERATION

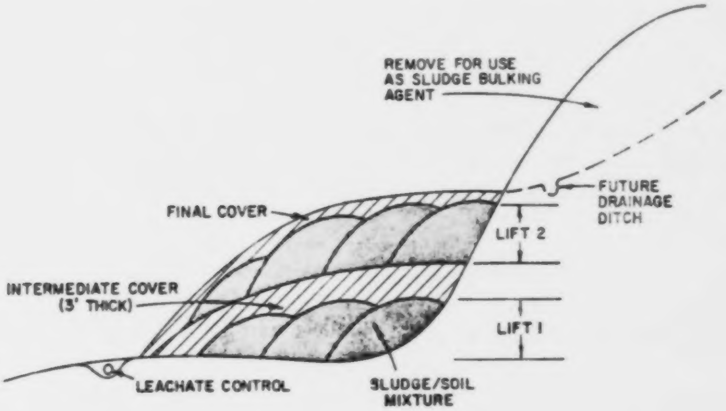


FIGURE 5-9

AREA FILL MOUND OPERATION

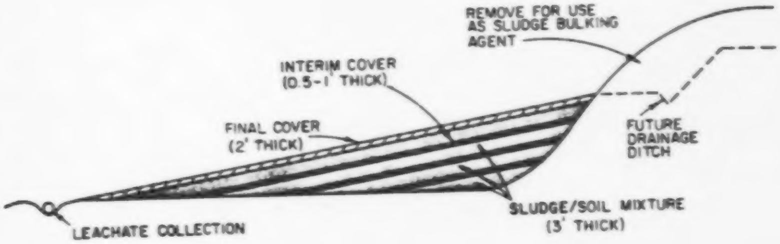
Sludge as received at the landfill is usually mixed with a bulking agent. The bulking agent absorbs excess moisture from the sludge and increases its workability. The amount of soil needed to serve as an additional bulking agent depends upon the solids content of the sludge. Generally the soil requirements shown in Table 5-7 may serve as a guideline. Fine sand appears to be the most suitable bulking agent because it can most easily absorb the excess moisture from the sludge.

5.6.2 Area Fill Layer

At area fill layer operations, sludge/soil mixtures are spread evenly in layers from 0.5 to 3 ft (0.15 to 0.9 m) thick. This layering usually continues for a number of applications. Interim cover between consecutive layers may be applied in 0.5 to 1 ft (0.5 to 0.3 m) thick applications. Final cover should be at least 1 ft (0.3 m) thick. An illustration of a typical area fill layer operation is included as Figure 5-10.

FIGURE 5-10

CROSS-SECTION OF TYPICAL AREA FILL LAYER OPERATION


REMOVE FOR USE AS SLUDGE BULKING AGENT
INTERIM COVER (0.5-1' THICK)
FINAL COVER (2' THICK)
FUTURE DRAINAGE DITCH
SLUDGE/SOIL MIXTURE (3' THICK)
LEACHATE COLLECTION

5.6.3 Diked Containment

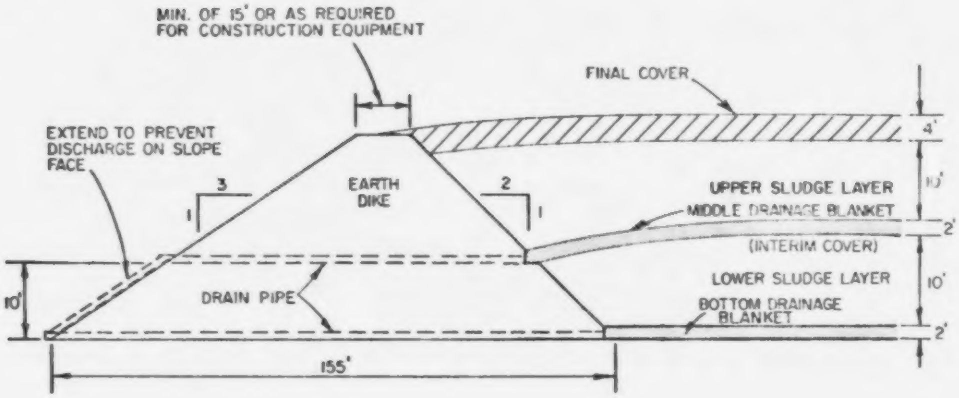
At diked containment operations, earthen dikes are constructed to form a containment area above the original ground surface. Dikes can be of various heights, but require side slopes of at least 2:1 and possibly 3:1. A 15 ft (4.6 m) wide road, covered with gravel should be constructed atop the dikes.

Sludge may be either (1) mixed with soil bulking for subsequent transport and dumping into the containment area by on-site equipment or (2) dumped directly into the containment area by haul vehicles without bulking soil. Large quantities of imported soil may be required to meet soil requirements for dike construction and bulking since diked containments are often constructed in high groundwater areas.

Sludge is dumped into diked containments in lifts before the application of interim cover. Often this interim cover is a highly permeable drainage blanket which acts as a leachate collection system for sludge moisture released from the sludge lift above. Final cover should be of a less permeable nature and should be graded even with the top of the dikes. An illustration of a typical diked containment operation is included as Figure 5-11.

FIGURE 5-11

CROSS-SECTION OF TYPICAL DIKED CONTAINMENT OPERATION



5.7 Codisposal Designs

Codisposal is defined as the receipt of sludge at a conventional landfill receiving municipal refuse. Two methods of codisposal have been identified: (1) sludge/refuse mixture and (2) sludge/soil mixture. Design considerations for codisposal landfills have been included in Table 5-8.

TABLE 5-8

DESIGN CONSIDERATIONS FOR CODISPOSAL OPERATIONS

Design Parameter	Consideration			
	Method	Bulking Agent	Sludge Solids Content	Bulking Ratio
Bulking Ratio	Sludge/refuse mixture	Refuse	3-10%	7 tons refuse:1 wet ton sludge
			10-17%	6 tons refuse:1 wet ton sludge
			17-20%	5 tons refuse:1 wet ton sludge
			> 20%	4 tons refuse:1 wet ton sludge
	Sludge/soil mixture	Soil	≥ 20%	1 soil:1 sludge

1 ton = 0.907 Mg

This manual does not provide all details on the design of a refuse landfill receiving sludge. Rather, only those design features which distinguish refuse landfills receiving sludge from those not receiving sludge are addressed. The EPA document, "Sanitary Landfill Design and Operation" [4] should be consulted for information relating to design and operation of a refuse landfill.

5.7.1 Sludge/Refuse Mixture

In a sludge/refuse mixture operation, sludge is delivered to the working face of the landfill where it is mixed and buried with the refuse. Most of the considerations relative to the receipt of sludge at refuse landfills are operational. These problems and solutions are described in Chapter 6, Operation. Nevertheless, some of the considerations require planning and design solutions. These are described in this section.

The first problem encountered at codisposal sites is sludge handling difficulty due to the liquid nature of sludge relative to refuse. Difficulties include (1) the sludge is difficult to confine at the working face since it will readily flow, and (2) equipment slips and sometimes becomes stuck in the sludge while operating at the working face. These difficulties can be minimized if proper planning is employed to control the quantity of sludge received at the refuse landfill. Every effort should be made not to exceed the absorptive capacity of the refuse. Obviously, the maximum allowable sludge quantity will vary depending largely on the quantity of refuse received and the solids content of the sludge. Some suggested bulking ratios for sludge/refuse mixtures at various sludge solids contents were included previously in Table 5-8. In any event determinations should be made on a site-by-site basis using test operations.

A second planning and design consideration for sludge/refuse mixture operations concerns leachate control. The impact of sludge receipt on leachate is highly site-specific. Generally, increased leachate quantities should be expected. Leachate control systems may have to be designed or modified accordingly.

A third planning and design consideration is storage for sludge received in off-hours. In many cases sludge is delivered around the clock, whereas, refuse delivery is confined to certain hours. Sludge storage facilities may have to be installed to contain sludge overnight or over weekends until sufficient refuse bulking is delivered.

5.7.2 Sludge/Soil Mixture

In a sludge/soil mixture operation, sludge is mixed with soil and applied as cover over completed refuse fill areas. Most of the considerations associated with these operations are also of an operational nature and are addressed in Chapter 6, Operation. However, at the planning and design stage, an area must be reserved for sludge/soil mixing. This area must be suifficiently sized and have sufficient soil available for sludge bulking. Information on a suggested bulking ratio was included in Table 5-8. The soils in this area must also be adequate to protect the groundwater.

5.8 Environmental Safeguards

Groundwater protection is the most difficult and costly environmental control measure required at many sludge landfills. Additionally, contamination of surface water must not be allowed. Other environmental considerations are methane gas migration and accumulation in nearby structures, odors, dust, vectors, and/or aesthetics. Presented below are design concepts that minimize or prevent adverse environmental impacts from leachate generation and methane gas migration. The other environmental controls are discussed in Chapter 6, Operations, since their control is more a function of operation than design.

5.8.1 Leachate Controls

Leachate can be generated simply from the excess moisture in the sludge as received at the landfill. Rainfall on the surface of the fill area can add a limited amount of water to the interred sludge. However, the surface of the landfill should be sloped enough to cause most of the rainfall to drain. Other storm water runoff must be diverted around the landfill, and the landfill must be located above historically high groundwater elevations. These positive controls will minimize the quantity of leachate to be generated. In dry areas where the rate of evaporation is much higher than the precipitation, zero infilration can result, thereby limiting the amount of leachate generated by the sludge. Table 5-9 details the range of constituent concentrations in leachate at sludge landfills. It should be emphasized that the leachate depends on the nature of the sludge interred. Moreover, if the site has been properly designed, these constituents can be effectively attenuated by soils or collected and subsequently treated.

TABLE 5-9

RANGE OF CONSTITUENT CONCENTRATIONS
IN LEACHATE FROM SLUDGE LANDFILLS [5]
(in mg/l unless otherwise indicated)

Constituent	Concentration	Constituent	Concentration
Cl	20-600	Hg	0.0011-0.0002
SO^4	1-430	Cu	0.02-37
TOC	100-15,000	Fe	10-350
COD	100-24,000	Pb	0.1-10
Ca	10-2,100	TKN	100-3,600
Cd	0.001-0.2	Fecal Coliform	2,400-24,000 MPN/100 ml
Cr	0.01-50	Fecal Streptococcus	2,100-240,000 MPN/100 ml
Zn	0.01-36		

Leachate may enter into the water system through essentially two pathways:

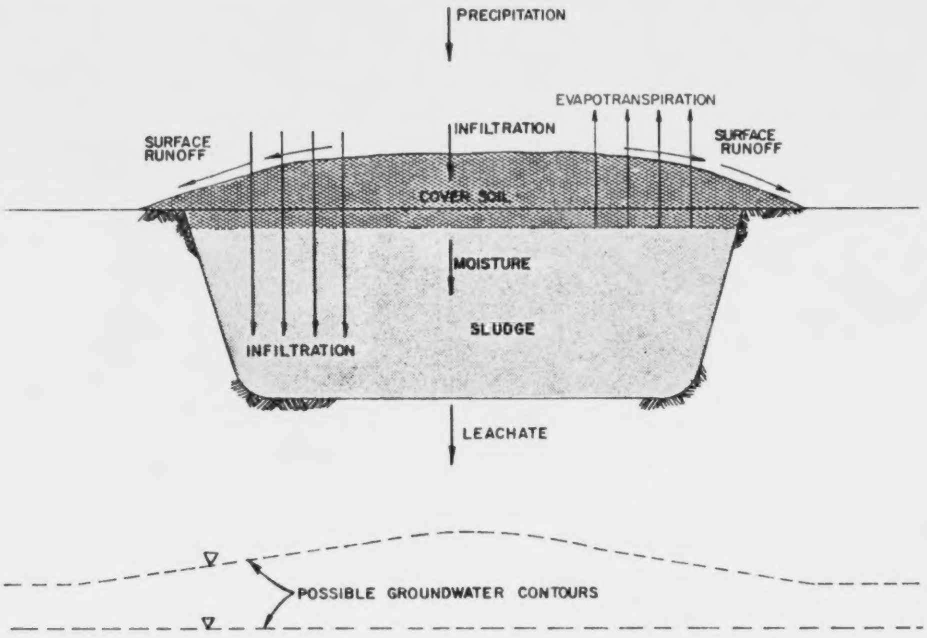
1. Percolation of the leachate, laterally or vertically, through soil into the groundwater aquifers (Figure 5-12)

2. Runoff of leachate outcroppings into surface waters

Careful site selection and attention to design considerations can prevent or minimize leachate contamination of groundwater and surface water. The control of leachate may be accomplished through:

FIGURE 5-12

WATER BALANCE AT SLUDGE LANDFILL



1. Natural conditions and attenuation
2. Imported soils or soil amendments used as liners and/or cover
3. Membrane liners
4. Collection and treatment

5.8.1.1 Natural Conditions and Attenuation

Leachate may be contained on-site due to natural hydrogeological and topographic conditions or through use of man-made facilities. Hydrogeological characteristics of the site affecting leachate containment are primarily the hydraulic conductivity of the underlying strata and the depth to usable groundwater.

Contaminants in leachate can be attenuated when passing through soils by physical-chemical, mechanical, and/or biological processes. The mechanisms by which these processes are performed include:

1. Filtration
2. Ion exchange
3. Adsorption
4. Chemical precipitation
5. Biodegradation
6. Complexation

The properties of the soil environment that influence the extent to which these mechanisms are operative [6][7] include:

1. Soil grain size
2. Organic content
3. Cation exchange capacity
4. pH
5. Eh
6. Hydrous oxides
7. Fill lime content

The relative importance of one property over another is not well documented. It is likely to vary from one situation to the next [8]. For example, some studies indicate that the cation exchange capacity (CEC) of clay minerals are the dominant removal mechanisms for some substances (K, NH_4, Mg, Si, and Fe), while precipitation was observed to be the principal attenuative mechanism for other substances (Pb, Cd, Hg, and Zn) [9]. Other studies have indicated that the following soil properties are most useful in attenuating pollutants from soils [9]:

1. Clay content
2. Content of hydrous oxides, primarily iron oxides
3. pH and content of free lime
4. Surface area per unit weight of soil

In another study [10], clay minerals were ranked according to their attenuating capacity. It was observed that montmorillonite attenuated pollutants four times better than illite and five times better than kaolinite. These ratios are nearly identical with the CEC for the three clays (Table 5-10) [6].

TABLE 5-10

ATTENUATION AND PERMEABILITY PROPERTIES OF CLAYS [6]

%	Material	Cation exchange capacity	Bulk density	Initial hydraulic conductivity[b]
		meq/100g	g/cm^3	cm/sec
0	Montmorillonite	0.0	1.71	1.27E-03
2	Montmorillonite	1.7	1.71	9.45F-04
4	Montmorillonite	3.3	1.77	4.34E-04
8	Montmorillonite	6.8	1.79	4.70E-04
16	Montmorillonite	13.3	1.87	1.22E-05
32	Montmorillonite	27.3	1.55	1.27E-06
64	Montmorillonite	50.7	1.23	3.05E-07
100	Montmorillonite	79.5	0.84	7.26E-07
2	Kaolinite	0.2	1.68	7.44E-04
4	Kaolinite	0.5	1.76	4.78E-05
8	Kaolinite	1.0	1.80	9.90E-04
16	Kaolinite	2.2	1.87	2.86E-05
16	Kaolinite	-	1.94	1.09E-06
32	Kaolinite	4.3	1.66	2.40E-06
64	Kaolinite	8.2	1.22	5.45E-07
100	Kaolinite	15.1	0.90	2.98E-07
4	Illite	0.7	1.80	8.17E-04
16	Illite	2.7	1.83	2.68E-05
8	Montmorillonite + 8 Kaolinite	7.6	1.95	5.35E-07
8	Kaolinite + 8 Illite	2.8	1.95	1.48F-06
8	Kaolinite + 8 Illite + 8 Montmorillonite	9.2	1.64	8.08F-06

---

[a] Quartz sand added to make 100%

[b] Exponential notation: E-03 means x 10^{-3}

The individual chemical constituents of the leachate examined in this study were ranked according to their degree of attenuation by the three clays as follows:

$$Cl < COD < Na < NH_4 < K < Mg < Si < Cd < Zn < Pb < Hg$$

In one of the previously mentioned studies [6], physical characteristics of representative whole soils from the major soil series in the United States were determined (Table 5-11). These data were correlated with the attenuative capacity of each soil. Results from these studies indicate that the clay content of a soil and the surface area per unit weight were by far the best single predictors of a soil's attenuation properties [9]. The relative rate of movement through the soil is also important in site design. Again, clay soils exhibit the slowest movement. In studies in Omaha, Nebraska, leachates travelled only 160 ft (50 m) in 58 years [5] through a clay soil.

TABLE 5-11

ATTENUATION PROPERTIES OF REPRESENTATIVE SOIL SERIES [6]

Series	Order[a]	Soil Waste pH	Cation Exchange Capacity	Electrical Conductivity of Extract	Column Bulk Density	Surface Area	Free iron oxides	Total Mn	Texture[b]			Major[c] Clay Minerals
									Sand	Silt	Clay	
			meg/100g	uhos/cm	g/cm^3	m^2/g	%	mg/l	%	%	%	
Wagram	Ultisol	4.2	2	225	1.89	8.0	0.6	50	88	8	4	Kaolinite, Chlorite
Ava	Alfisol	4.5	19	157	1.45	61.5	4.0	360	10	60	31	Vermiculite, Kaolinite
Kalkaska	Spodosol	4.7	10	237	1.53	8.9	1.8	80	91	4	5	Chlorite, Kaolinite
Davidson	Ultisol	6.2	9	169	1.89	51.3	17.0	4100	19	20	61	Kaolinite
Molokai	Oxisol	6.2	14	1262	1.44	67.3	23.0	7400	23	25	52	Kaolinite, Gibbsite
Chalmers	Mollisol	6.6	26	288	1.60	125.6	3.1	330	7	58	35	Montmorillonite, Vermiculite
Nicholson	Alfisol	6.7	37	176	1.53	120.5	5.6	950	3	47	49	Vermiculite
Fanno	Alfisol	7.0	33	392	1.48	122.1	3.7	280	35	19	46	Montmorillonite, Mica
Mohave	Aridisol	7.3	10	615	1.78	38.3	1.7	825	52	37	11	Mica, Kaolinite
Mohave (calcareous)	Aridisol	7.8	12	510	1.54	127.5	2.5	770	32	28	40	Mica, Montmorillonite
Anthony	Entisol	7.8	6	328	2.07	19.8	1.8	275	71	14	15	Montmorillonite

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[a] U.S. Department of Agriculture Comprehensive Soil Classification System.

[b] U.S. Department of Agriculture System: Sand, 2mm - 0.05 mm; Silt, 0.05mm - 0.002mm; Clay, 0.002 mm diameter.

[c] The dominant mineral is listed first.

Although the capacity of soils to attenuate leachate is a site selection and design consideration, the long term effectiveness of the contaminant removal processes is not verified. A soil that offers moderately low permeability, a high clay content, high CEC, and relatively high pH (>6.0), is preferred over soils composed of coarse-grained particles with high permeabilities and low CEC values.

Information on soil properties can be obtained from several sources, but the Soil Conservation Service (SCS) soil surveys are the primary source. Well logs can also offer additional data on soils and geology. Soil surveys will normally provide soil maps delineating the apparent boundaries of soil series with their surface texture. A written description of each soil series provides limited information on chemical properties, engineering applications, interpretive and management information, slopes, drainage, erosion potentials, and general suitability for most kinds of crops grown in the particular area. Additional information on soil characteristics and information regarding the availability of soil surveys can be obtained directly from the SCS. The SCS serves as the coordinating agency for the National Cooperative Soil Survey, and as such, cooperates with other government agencies, universities, and agricultural extension services in obtaining and distributing soil survey information [11]. For insufficient data and/or for site specific verification, tests should be performed on site by experienced soil scientists.

The methods of determining some of these various soil properties are presented in Table 5-4. Others may be ascertained from any number of texts [12][13][14].

5.8.1.2 Imported Soils and Soil Amendments

If clayey soil exists only on a part of the site or at certain depths, these suitable soils can be selectively excavated and used to line the sludge landfill. It is highly desirable to use on-site soils to the maximum extent possible to save the cost of purchasing and hauling soils to the site. However, if on-site soils and other conditions are not adequate to contain leachate or attenuation is inadequate to protect groundwater, soil permeabilities can be lowered by the addition of imported clays or polymeric materials. Clay minerals such as montmorillonite or bentonite and artificial soil amendments are available commercially if sufficient quantities of natural clay are not present on site. In areas of high rainfall, it will be necessary to incorporate leachate collection systems into the design to prevent water from ponding.

The basic procedure for incorporating permeability-reducing soil additives follows [15]:

1. Select the most cost-effective soil additive. Determine the rate of application of the additive. This rate is based on characteristics of the existing soil (e.g., soil particle size and void space). The amount of additive should be such that the amended soil has a permeability of 10^{-6} to 10^{-7} cm/sec. Usually it is advisable to have an independent soil testing lab identify the most cost effective soil amendment and mix, but the proper mix can be determined empirically by taking core samples and adding various mixes of soil amendments. The data may then be plotted on a graph and the mixes required for the desired permeability established. It is often useful to determine the plasticity of the mix in addition to the permeability.

2. Prepare and grade the site. Remove all tree roots, branches, rocks or other items that may penetrate the amended soil layer. The bottom of the site should be graded to allow the leachate to drain to a centralized collection point.

3. Apply the additive and disc it into the existing soil to a depth of approximately 12 in. (30 cm). The depth of artificially applied or amended soil liners is best determined on a case-by-case basis to obtain a safe yet cost-effective design.

4. Compact the soil-additive mixture to assure a watertight barrier through differential settlement.

5. Flood the area with water to completely saturate the amended soil. Clayey materials are very impermeable to water movement when moist but can develop cracks when dry. Thus, clay liners must be kept moist prior to depositing sludge to ensure integrity.

6. Cover the clay liner with a 12 in. (30 cm) layer of native soil to protect it during the landfilling operation.

5.8.1.3 Membrane Liners

The use of membrane liners for containment of leachate has received attention in the literature [16][17][18][19][20], and may be practical for application at area fill and wide trench operations. Liners should be used when soil permeabilities or soil depths are not adequate to protect the groundwater or when required by State regulations. It is preferable to use in situ soils whenever possible. However, when available site conditions or laws dictate that a liner must be used, many types of membrane and other thin layer liners are currently available, as indicated in Table 5-12.

TABLE 5-12

LINERS FOR SLUDGE LANDFILLS [16]

- Asphalt compositions
    - Asphaltic concrete
    - Hydraulic asphaltic concrete
    - Preformed asphaltic panels laid on concrete surfaces
    - Catalytically blown asphalt sprayed on soil
    - Emulsified asphalt sprayed on soil or on fabric matting
    - Soil asphalt mixtures
    - Asphalt seals
- Portland cement compositions
    - Concrete with asphalt seals
    - Soil cement with asphalt seals
- Soil sealants
    - Chemical (soil amendments)
    - Lime
    - Rubber and plastic latexes
    - Penetrating polymeric emulsions
- Liquid rubbers sprayed
    - Rubber and plastic latexes
    - Polyurethanes
- Synthetic polymeric membranes
    - Butyl rubber
    - Ethylene propylene rubber (EPDM)
    - Chlorosulfonated polyethylene (Hypalon)
    - Chlorinated polyethylene (CPE)
    - Polyvinylchloride (PVC)
    - Polyethylene (PE)

Synthetic polymeric and asphaltic materials are the most common membrane liners used for landfills. Factors to consider in selecting a liner are:

1. Effectiveness (It appears that some materials may not be acceptable for use with certain wastes [21]. Before selecting a liner, pretesting or literature review should be performed.)
2. Cost, both acquisition and installation (Table 5-13)
3. Installation time
4. Durability

TABLE 5-13

ESTIMATED COSTS FOR LANDFILL LINERS [16]
(Note: Figures presented are 1973 costs)

Item	Thickness, mils	Price of roll goods ($/yd^2)	Installed cost[a] ($/yd^2)
Butyl rubber	31.3 (1/32")	$2.25	$3.25-$4.00
Chlorinated polyethylene (CPE)	20	1.58	$2.43- 3.24
Chlorosulfonated polyethylene[b]	20	1.66	2.88- 3.06
Ethylene propylene rubber (EPDM)	46.9 (3/64")	2.42	2.65- 3.42
Neoprene	62.5 (1/16")	2.97	4.41- 5.40
Polyethylene film	10	0.36	0.90- 1.44
Polyvinyl chloride	20	0.90	1.17- 2.16
Soil + Bentonite 9 lb/yd^2 (1 psf)			$0.72
Soil cement 6 in. thick + sealer (2 coats--each 0.25 gal/yd^2)			1.25
Soil asphalt 6 in. thick + sealer (2 coats--each 0.25 gal/yd^2)			1.25
Asphalt concrete--Dense-graded paving with sealer coat (Hot mix--4-in. thick)			2.35- 3.25
Asphalt concrete-Hydraulic (Hot mix--4-in. thick)			3.00- 4.20
Bituminous seal (catalytically blown asphalt) 1 gal/yd^2			1.50- 2.00 (with earth cover)
Asphalt emulsion on mat (Polypropylene mat sprayed with asphalt emulsion)			1.26- 1.87

[a] Soil cover not included; membranes require some soil cover, cost of which can range from $0.10 to $0.50/yd^2 per ft of depth

[b] Hypalon, with nylon scrim

1 lb = 0.454 kg
1 yd^3 = 0.7646
1 gal = 3.785 L
1 in. = 2.54 cm
1 yd^2 = 0.8361 m^2

Since most area fill landfills extend over a relatively large area, membrane liners usually must be spliced during field installation. Thus, seam durability and the amount of overlap should be considered in membrane design. Design of a membrane/liner follows roughly the same procedures identified for clay barriers:

1. Select a membrane based on the above noted considerations (effectiveness, cost, installation time, and durability)
2. Prepare and grade the soil surface
3. Compact the soil surface
4. Install the liner
5. Cover the liner with at least 12 in. (30 cm) of porous soil. If equipment is to be operated over the sludge or refuse is disposed, more cover may be required

It should be noted that liners have potential disadvantages, including:

1. The expected life of liners has not been established. Liners have been used at landfills over a relatively short period (less than 10 yrs), whereas effectiveness must be assured for many decades.
2. Sludge disposal operations can tear the liner, causing leachate seepage.
3. Changes in the hydraulic conductivity of the underlying or surrounding soil cause the groundwater to rise, which exerts upward pressure on the liner.
4. Once the liner is in place and sludge is deposited, membrane failure cannot be easily detected or readily repaired.

Changes in hydraulic conductivity and evaporation result when the area is excavated and the overburden removed. The problems associated with a rising water table can be mitigated by placing a leachate collection system beneath liners. Although expensive, this will relieve pressure on the liners and, if properly placed, enable the presence and locations of leaks to be identified.

5.8.1.4 Collection and Treatment

If the site design includes provisions for leachate containment, a leachate collection system must be installed. The collection system may consist of a sump into which leachate collects and is subsequently pumped to a holding tank or pond. Leachate may also be collected by a series of drain pipes or tiles which intercept and channel the leachate to the surface or to a sump. Figure 5-13 depicts representative collection systems. Groundwater interceptor trenches may be used to lower the water table in the vicinity of the fill area (Figure 5-14).

FIGURE 5-13

UNDERDRAIN FOR LEACHATE COLLECTION

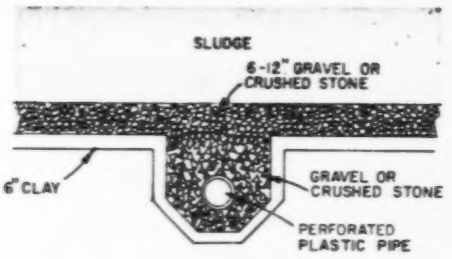
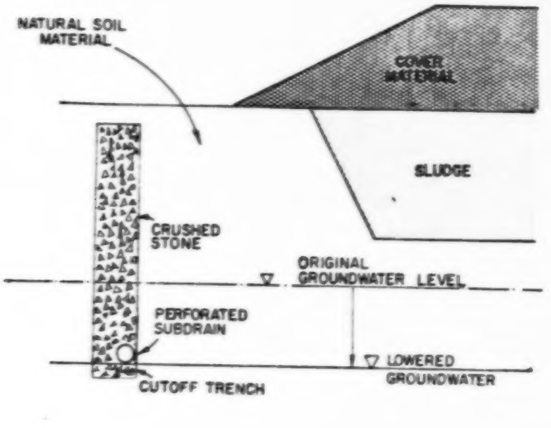


FIGURE 5-14

UPGRADIENT GROUNDWATER INTERCEPTOR TRENCH



Collected leachate may be treated by one or more of the following methods:

1. Discharge to a wastewater collection system or haul directly to a treatment plant
    a. biological treatment
    b. physical-chemical treatment
2. Recycle through the landfill
3. Evaporation of leachate in collection ponds
4. On-site treatment

Depending on the leachate characteristics, volume, and local regulations, it may be possible to discharge collected leachate to an existing wastewater system for subsequent treatment with municipal wastewater. Local wastewater treatment plant personnel should be consulted for leachate acceptability to determine special requirements for discharge to the treatment plant; e.g., large slugs of highly contaminated leachate may have to be mixed with municipal wastewater to prevent plant upsets.

Leachate collected from relatively new landfills is best treated by biological processes (Table 5-14) [22]. Physical-chemical treatment processes are most effective in treating leachate from landfills containing stabilized sludge or in removing organic matter from sludge from biological treatment units. Activated carbon and reverse osmosis show promise for removing organic matter, but their viability on a large scale over extended periods has not been verified.

TABLE 5-14

EXPECTED EFFICIENCIES OF ORGANIC REMOVAL FROM LEACHATE [22]

Character of Leachate				Effectiveness of Treatment Processes			
COD/TOC (mg/l)	BOD/COD (mg/l)	Age of fill	COD (mg/l)	Biological treatment	Chemical precipitation (mass lime dose)	Chemical oxidation Ca $(ClO)_2$	O_3
>2.8	>0.5	Young (<5 yr)	>10,000	Good	Poor	Poor	Poor
2.0-2.3	0.1-0.5	Medium (5-10 yr)	500-10,000	Fair	Fair	Fair	Fair
<2.0	<0.1	Old (<10 yr)	<500	Poor	Poor	Fair	Fair

If discharge to the wastewater system is not practical or if the leachate is potentially disruptive to treatment plant operations, on-site treatment or transportation to a chemical waste disposal site will have to be utilized.

On-site treatment may consist of recycling the leachate through the landfill, placing the leachate in a shallow basin to allow it to evaporate, or installing a small (specially designed) treatment plant on site. The latter alternative should be avoided if at all possible due to its high cost and the unproven reliability of such small plants.

Leachate recycling has been shown to be useful because it [23]:

1. Promotes rapid development of anaerobic decomposition in the wastes
2. Increases the rate and predictability of biological stabilization
3. Reduces the volume of leachate to be handled by evaporation of the water during dry periods

However, leachate recycling systems are not feasible at most sites; specifically, areas with high rainfalls and high application rates are not suitable. Its primary application should be restricted to codisposal sites in climates where the evaporation rate exceeds rainfall to a significant extent.

It may be valuable to have contingency plans designed to intercept a downgradient leachate plume. Essentially this would consist of a number of downgradient wells which could be pumped, thus containing the plume. The extracted water may be treated and discharged.

5.8.2 Gas Controls

Gas is produced by the decomposition of organic matter in sludge. The primary gases of decomposition are methane and carbon dioxide. Some nitrogen and oxygen is found. Traces of ammonia, hydrogen sulfide, hydrogen, and volatile organic species are sometimes found in landfills. The amount and composition of gases produced depends on the quantity and characteristics of sludge deposited, the amount of moisture present, and other factors. Ranges of gas concentrations that may be expected are shown in Table 5-15 [5].

TABLE 5-15

GAS CONCENTRATIONS AT SELECTED SLUDGE LANDFILLS [5]
(% of sample)[a]

	Sludge-Only			Codisposal			
	1	2	3	4	5	6	7
CH_4	55	56	48	50	43	59	54
CO_2	41	39	20	37	50	40	32
O_2	1	1	7	2	1	-	3
N_2	3	3	24	10	5	1	10

[a] Totals may not add to 100 due to rounding.

The rate and types of gas generated depends on the type of microbial (biological) decomposition occuring. The amount of gas generated from sludge decomposition can be expected to range from 16 to 18 ft^3/lb (1 to 1.1 m^3/kg) of volatile matter reduced [24]. Five to 8 ft^3/lb (0.3 to 0.5 m^3/kg) of gas is generated from deposited municipal solid waste). Raw sludges probably generate somewhere between 8 and 16 ft^3/lb of dry solids. Digested sludges would be expected to generate considerably less gas since most of this gas quantity was generated in the digestors. Of course, for all the rates noted above (for refuse as well as raw and digested sludges) it should be noted that the gas is generated over an extended period that may exceed fifty years.

Methane, like carbon dioxide, is odorless; unlike carbon dioxide, methane is relatively insoluble in water. However, when methane is present in air at between 5 and 15% concentrations, and is confined in an enclosed area, it may be explosive. Methane can move by diffusion through the sludge into the atmosphere where it is harmlessly dissipated. The gas can also move laterally from the landfill into surrounding soils, especially if the cover material is relatively impermeable. Through lateral movement, methane could seep into nearby buildings or utilities. A build-up of methane to a concentration within the explosive limits is hazardous. Migrating gas can also damage vegetation surrounding a sludge landfill by excluding oxygen from the root zone [25][26]. The cover soil can be used to control gas migration and odor from the sludge. Chapter 6 (Operation) and Chapter 8 (Completed Site) discuss in detail the proper placement of cover soil.

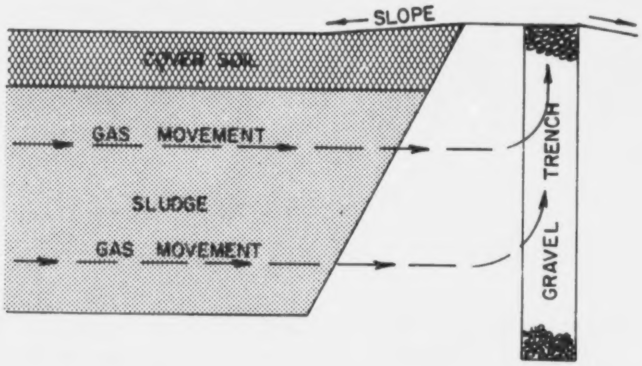
Installation of gas control facilities is not necessary if the site is isolated and will remain isolated from inhabited structures. However, when inhabited structures are near the landfill, and monitoring wells indicate that a structure is threatened, gas migration controls are required. Migration can be controlled by installing barriers to gas flow and/or by collecting and venting the gas. Gas control techniques can generally be classified into permeable and impermeable methods.

5.8.2.1 Permeable Methods

Permeable methods (Figure 5-15) usually entail installing a gravel-filled trench outside the filled area. The trench intercepts migrating gas and vents it into the atmosphere. A forced vacuum extraction system in trenches or in wells is sometimes appropriate.

FIGURE 5-15

PERMEABLE METHOD OF GAS MIGRATION CONTROL



5.8.2.2 Impermeable Methods

Placing a barrier of very low permeability material around the perimeter of the landfill minimizes lateral gas migration. The movement of gas through soils can be controlled by using materials that are more impermeable than the surrounding soil.

The most common material used for construction of gas barriers is compacted clay. A clay layer approximately 2 ft (0.6 m) thick is probably adequate (if it can be constructed that thin). Often a thicker layer is required in order to ensure an adequate seal if the sideslope exceeds

2H:1V. To be effective, the clay layer must be continuous; it cannot be penetrated. The clay liner should be constructed as the fill progresses, because prolonged exposure to air will dry the clay and cause it to crack. Synthetic membranes may be considered for the control of migrating gas but their effectiveness has not been established. PVC is thought to be the most effective.

5.8.2.3 Gas Extraction Systems

An effective method of gas control in refuse landfills involves the placement of an impermeable barrier combined with a gas extraction system via strategically located forced exhaust vents. However, such systems are not suitable for sludge landfills because the high moisture content typically found in sludge does not permit gas movement and sludge can enter and clog the evacuation pipes.

A few gas recovery systems have been installed at large refuse landfills to recover methane gas. Gas recovery has not been attempted at sludge landfills and is probably not feasible at this time; to be viable, the landfill must be very large; e.g., more than 5,000,000 tons (450,000,000 Mg) for a refuse landfill. Sludge landfills are normally much smaller than this.

5.9 Storm Water Management

All upland drainage should be collected and directed around the landfill. Drainage may be channeled through the landfill via an enclosed pipe, but only if absolutely necessary. The drainage channels may be constructed of earth (Figure 5-16), corrugated metal pipe (CMP) (Figure 5-17), gunite-lined earthen ditches, or stone-lined ditches (Figure 5-18). If the access or on-site roads of the landfill are paved, they may be used to channel drainage across a landfill. It is important to note that the dimensions shown are representative. Actual dimensions for constructing drainage structures should be based on on-site investigations of runoff potential.

On the sludge landfill itself, all active and completed site working areas should be properly graded. The surface grade should be greater than 2% to promote runoff and inhibit ponding of precipitation, but less than 5% to reduce flow velocities and minimize soil erosion. If necessary, siltation ponds should be constructed to settle the solids contained in the runoff from the site. Straw bales, berms, and vegetation may supplement ponds or be used in conjunction with them to

FIGURE 5-16

EARTHEN DRAINAGE CHANNEL

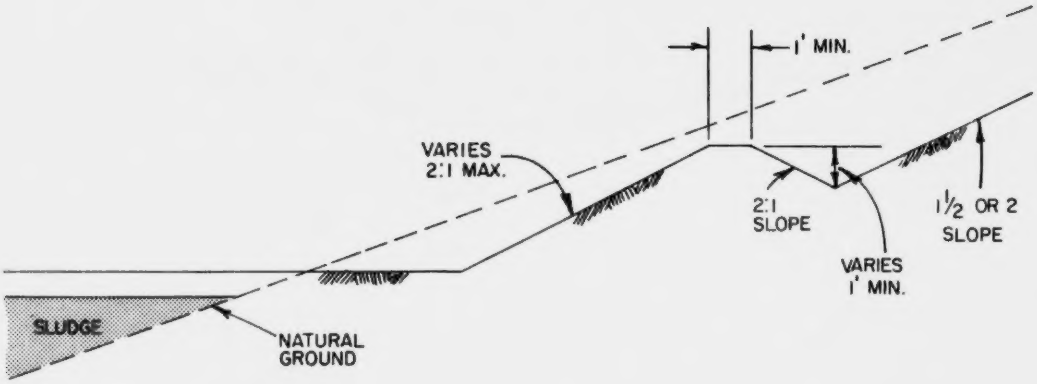


FIGURE 5-17

CMP DRAINAGE CHANNEL

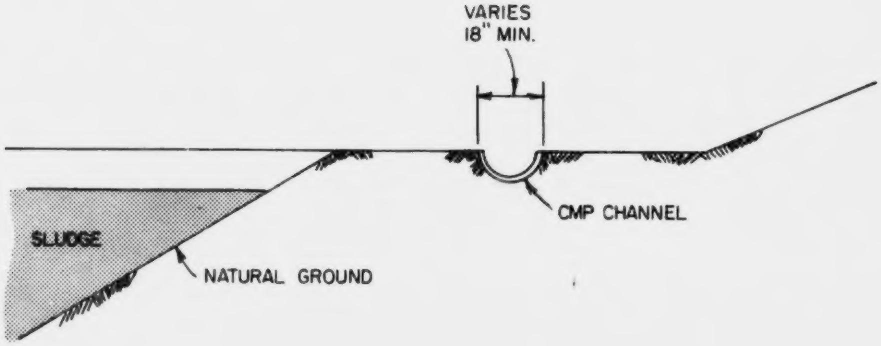
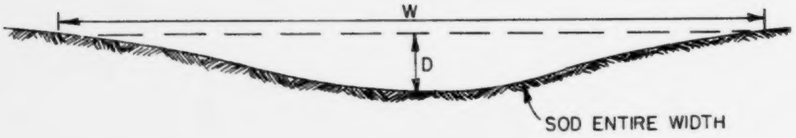
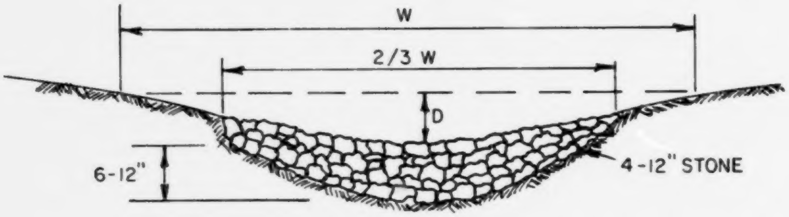


FIGURE 5-18

STONE DRAINAGE CHANNELS



SODDED WATERWAY



WATERWAY WITH STONE CENTER DRAIN

control runoff and siltation on the site. Since the location of fill areas is constantly changing, portable drainage structures may be more economical than permanent facilities.

5.10 Access Roads

As a minimum, a permanent road should be provided from the public road system to the site. For larger landfills, the roadway should be 20 to 24 ft (6 to 7 m) wide for two-way traffic. For smaller operations a 15 ft (5 m) wide road can suffice. As a minimum, the roadway should be gravel-surfaced in order to provide access regardless of weather conditions. Grades should not exceed equipment limitations. For loaded vehicles, most uphill grades should be less than 7% and downhill grades less than 10%.

Temporary roads are used to deliver the sludge to the working area from the permanent road system. Temporary roads may be constructed by compacting the natural soil present and by controlling drainage, or by topping them with a layer of gravel, crushed stone, cinders, crushed concrete, mortar, bricks, lime, cement, or asphalt binders to make the roads more serviceable.

5.11 Other Design Features

5.11.1 Soil Availability

The quantity and adequacy of on-site soil for use as a bulking agent and for covering sludge will have been determined during the site selection process. However, the logistics of soil excavation, stockpiling, and consumption are more thoroughly evaluated during design. Excavation and stockpiling of soil must be closely coordinated with soil use for the following reasons:

1. Soil determined to be suitable for use and readily excavated may be located in selected areas of the site. The excavation plan should designate that these areas be excavated before filling has proceeded atop them.
2. Accelerated excavating programs may be desirable during warm weather to prevent the need to excavate frozen soil during cold weather.
3. Soil stockpiles should be located so that runoff will not be directed into future adjacent excavations and/or sludge filling areas and to minimize erosion.

5.11.2 Special Working Areas

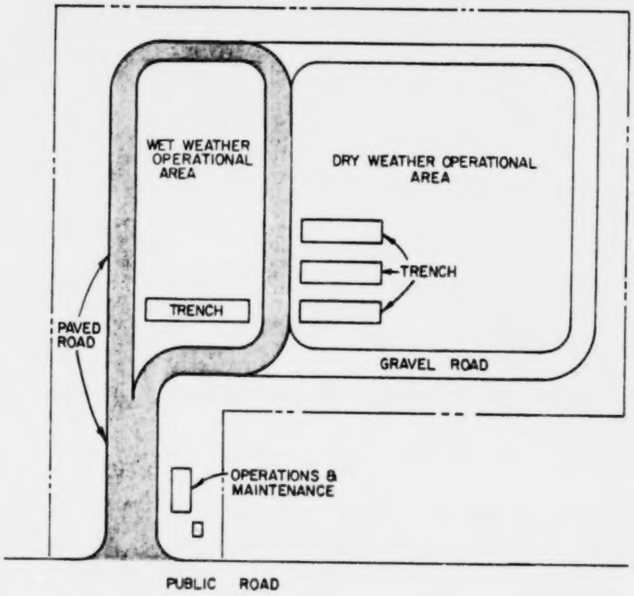
Special working areas should be designated on the site plan for inclement weather or other contingency situations. Access roads to these areas should be of all-weather construction and the area kept grubbed and graded. Arrangements for special working areas may include locating such areas closer to the landfill entrance gate (see Figure 5-19).

5.11.3 Buildings and Structures

At larger sludge landfills or where climates are extreme, a building should be provided for office space and employee facilities. Since

FIGURE 5-19

SPECIAL WORKING AREA



sludge landfills operate year round, regardless of weather, some protection from the elements should be provided for the employees. Sanitary facilities should be provided for both landfill and hauling personnel. At a few of the largest landfills, a building might be provided for equipment storage and maintenance. At smaller landfills, buildings cannot be justified, but trailers may be warranted.

Buildings on sites that will be used for less than 10 years can be temporary, mobile structures. The design and location of all structures should consider gas movement and differential settlement caused by decomposing sludge.

Scales are seldom used at sludge landfills. Normally, a relatively accurate estimate of fill quantities is available from the wastewater treatment plant(s) that generate the sludge.

5.11.4 Utilities

Larger landfills should have electrical, water, communication, and sanitary services. Remote sites may have to extend existing services or use acceptable substitutes. Portable chemical toilets can be used to avoid the high cost of extending sewer lines; potable water may be trucked in; and an electric generator may be used instead of having power lines run into the site.

Water should be available for drinking, dust control, washing mud from haul vehicles before entering the public road, and employee sanitary facilities. A sewer line may be desirable, especially at large sites and at those where leachate is collected and treated with domestic wastewater. Telephone or radio communications may be necessary since accidents or spills can occur that necessitate the ability to respond to calls for assistance.

5.11.5 Fencing

Access to landfills should be limited to one or two entrances that have gates that can be locked when the site is unattended. Depending on the topography and vegetation on the site and adjoining areas, entrance gates may suffice to prevent unauthorized vehicular access. At some sites it is desirable to construct periphery fences to keep out any trespassers and animals, which is an especially important consideration.

Fencing requirements will be greatly influenced by the relative isolation of the site. Sites close to housing developments may require fencing to keep out children and to provide a visual screen for the landfill. Landfills that are in relatively isolated rural areas may require a less sophisticated type of fencing or only fencing at the entrance and other places to keep out unauthorized vehicles.

If vandalism and trespassing are to be discouraged, a 6-ft (1.8-m) high chain link fence topped with a barbed wire guard is desirable (although expensive). A wood fence or a hedge may be used to screen the operation from view. A 4-ft (1.2-m) high barbed wire fence will keep cattle or sheep off the site. Keeping trespassers and animals off sludge landfills is more important than for refuse landfills because the sludge may not be sufficiently stable to support their weight.

If the sludge is being disposed of at a refuse landfill the fencing will also contain litter to some degree.

5.11.6 Lighting

If dumping operations occur at night, portable lighting should be provided at the operating area. Alternatively, lights may be affixed to haul vehicles and on-site equipment. These lights should be situated to provide illumination to areas not covered by the regular headlights of the vehicle.

If the landfill has structures (employee facilities, administrative offices, equipment repair or storage sheds, etc.), or if there is an access road in continuous use, permanent security lighting might be desirable.

5.11.7 Wash Rack

For landfills where operational procedures call for frequent contact of equipment with the sludge, a cleaning program should be implemented. Portable steam cleaning units or high pressure washers may be used. A curbed wash pad and collection basin may be constructed to collect and contain contaminated wash water. The contaminated water may be either pumped to a septic tank/soil absorption system or dispersed with the sludge. The washing facility should be used to clean mud from haul vehicles, to keep sludge and mud off the highway.

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CHAPTER 6

OPERATION

6.1 Purpose and Scope

The purpose of this chapter is to introduce an approach for implementing the design plans into an effective sludge landfill operation. The operation of a sludge landfill can be viewed as an ongoing construction project. As with any construction project, it must proceed according to detailed plans. Unlike conventional construction, however, the operating parameters of a sludge landfill are often changing and may require innovative alterations and contingency plans. An effective operation requires a detailed operational plan and a choice of equipment compatible with the sludge characteristics, the site conditions, and the landfilling method.

For the purposes of this chapter, the site operation may be viewed in two parts: the first part concerns operational procedures that are specific to the landfilling method; the second part concerns general operational procedures that are independent of the landfilling method.

6.2 Method-Specific Operational Procedures

Procedures dependent on the landfilling method include:

1. Site preparation
2. Sludge unloading
3. Sludge handling and covering

Because these procedures vary for each landfilling method, they will be discussed as functions of the landfilling methods introduced in Chapter 3.

6.2.1 Sludge-Only Trench

For sludge-only trenches, subsurface excavation is required so that sludge can be placed entirely below the original ground surface. In trench applications, the sludge is usually dumped directly into the trench from haul vehicles. Soil is not used as a sludge bulking agent. Soil is used as cover, usually in a single, final application.

Two kinds of sludge-only trenches have been identified including (1) narrow trench and (2) wide trench. Narrow trenches have widths less than 10 ft (3.0 m). Wide trenches have widths greater than 10 ft (3.0 m). Chapter 3 (Sludge Characteristics and Landfilling Methods) and Chapter 5 (Design) should be consulted for specific design criteria.

6.2.1.1 Site Preparation

Site preparation includes all tasks which are required prior to the receipt of sludge. Tasks include clearing and grubbing, grading the site, constructing access roads, and excavating trenches.

The location of access roads depends on the topography and the land utilization rate. Narrow trenches use land rapidly and require more extensive road construction. Wider and/or longer trenches may require vehicle access roads along both sides of the trench.

Prior to grading, the area should be cleared and grubbed. Grading should be done on the site (1) to control runoff and (2) to provide grades compatible with equipment to be used. For example, drag lines and trenching machines operate more efficiently on level surfaces. Narrow trenches may require less grading due to their applicability to hilly terrain.

Progressive trench construction is the most efficient procedure for a narrow trench operation. The initial trench is constructed using appropriate equipment and the soil either (1) piled along the length of the trench, or (2) stockpiled in a designated area, or (3) graded to ground level. Soil is often piled on the uphill side of the trench and used to prevent runoff from entering the trench. Succeeding trenches are constructed parallel to the initial trench. The trench dimensions and the distance between the trenches should follow design specificiations.

Trenches may require dikes positioned intermittently across the width of the trench, especially if such trenches are long. The dikes should be of sufficient height to contain the sludge and attendant liquids and allow proper trench filling and covering. Equipment may be used inside wide trenches to construct dikes.

On-going site preparation is critical for proper execution of a trenching operation. Depending on the quantity of sludge received, a designated trench volume should always be maintained in advance of filling operations. Ideally, trenches should be prepared at least one week ahead of the current landfilling operation.

6.2.1.2 Sludge Unloading

Signs should be placed to designate which trench is in use. Sludge is usually unloaded from haul vehicles via direct dumping. However, metal extension chutes or pumping may also be employed. If direct dumping is employed, an appropriately sized area should be prepared at the lip of the trench so that transport vehicles can safely back up to the trench edge for unloading. Sludge unloading can occur along the length of both sides of the trench if necessary. The entire unloading area should be kept clear of discharged sludge and periodically regraded to facilitate safe unloading operations.

6.2.1.3 Sludge Handling and Covering

Sludge should be uniformly distributed throughout the trench. Otherwise, depressions that could cause ponding are likely to occur as the fill settles. Narrow and wide trenches should be filled only to a level where a sludge overflow will not occur due to displacement during cover application. Markers on trench sidewalls can be used for this purpose. The appropriate level for sludge filling can best be established via experimentation using test loads.

Concurrent excavation, filling, and covering of trenches is a sequential operation that requires a coordination of effort. When the sludge has filled the trench to the designated level, cover material should be applied using either soil freshly excavated from a parallel trench or soil stockpiled during excavation of the trench being filled. Depending upon the solids content of the sludge and the width of the trench, cover application should proceed as follows:

1. If the sludge has a solids content from 15 to 20%, the width of the trench should be 2 or 3 ft (0.6 to 0.9 m). Cover application should be via equipment based on solid ground adjacent to the trench. Covering equipment may include a backhoe with loader, excavator, or trenching machine.
2. If the sludge has a solids content from 20 to 28%, the width of the trench is technically unlimited. However, it is limited by the requirement that cover be applied by equipment based on solid ground. Covering equipment may include a backhoe with loader, excavator, track loader, or dragline.

3. If the sludge has a solids content of 28% or above, the width of the trench is unlimited. Cover application can be via equipment which proceeds out over the trench pushing cover over the sludge. Covering equipment usually is a track dozer.

In all cases, initial layers of cover should be carefully applied to minimize sludge displacement. The final cover should extend at least 1 ft (0.3 m) above the ground surface (and preferably more). As settling occurs, additional soil cover may have to be applied to prevent depressions and ponding. Experience has shown that the majority of settlement occurs within 6 to 9 months. After it has settled, the entire trenched area should be graded. The trench areas should be sloped to minimize infiltration and prevent ponding. If practical, an impermeable cover (clay, etc.) should be applied to reduce infiltration. Final covers may include 1 to 2 ft (0.3 to 0.6 m) of topsoil and suitable vegetation such as grasses. A sludge soil mixture of 2 to 10 parts soil to 1 part sludge can be used to enrich the soil if necessary.

6.2.1.4 Operational Schematics

The preceding information has been included to generally describe the operation of trenches. Figures 6-1 through 6-4 illustrate specific trench operations.

6.2.2 Sludge-Only Area Fill

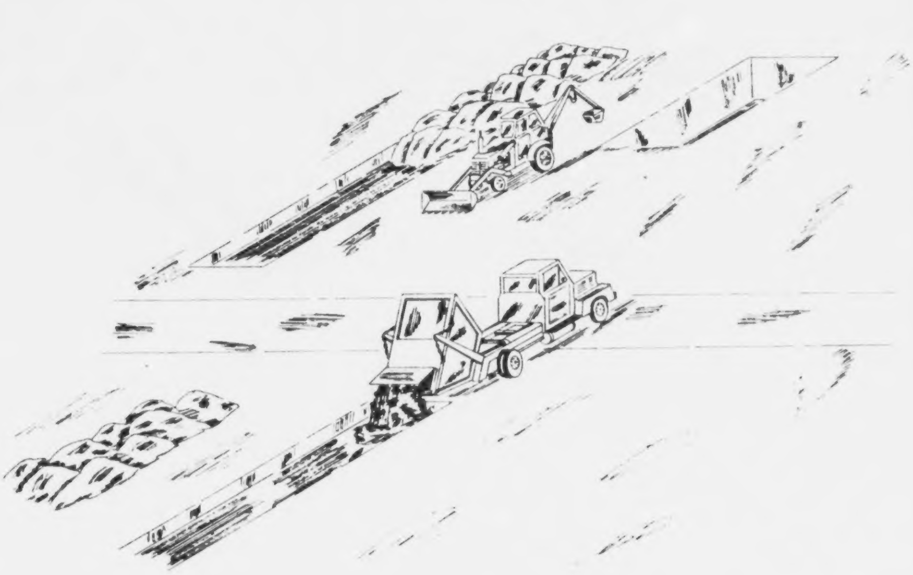
For sludge-only area fills, sludge is usually placed above the original ground surface. In area fill applications, soil is usually mixed with the sludge as a bulking agent. Cover may be used in both interim and final applications.

Three kinds of sludge-only area fills have been defined including (1) area fill mound, (2) area fill layer, and (3) diked containment. In area fill mound operations, sludge/soil mixtures are usually stacked into piles approximately 6 ft (1.8 m) high. In area fill layer operations, sludge/soil mixtures are spread evenly in layers 0.5 to 3 ft (0.15 to 0.9 m) thick. In diked containment operations, sludge (with or without bulking soil) is dumped into pits contained by dikes constructed above the ground surface. Chapters 3 and 5 should be consulted for specific design criteria.

FIGURE 6-1

NARROW TRENCH OPERATION

A sludge landfill in Paris, Maine receives 55 wet tons (50 Mg) per day of stabilized 14% solids sludge. Trenches at the site are 6 ft (1.8 m) wide and 6 to 8 ft (1.8 to 2.4 m) deep. From 4 to 10 ft (1.2 to 3.0 m) of undisturbed ground is maintained between trenches. Sludge is off-loaded directly into trenches from load-lugger trucks with arm-extended dump buckets. Unloading occurs either at the end of the trench or along its length. The sludge is filled to within 2 ft (0.6 m) of the surface and allowed to settle for several days before the trench is covered. This is necessary because the low solids sludge will not support cover initially. Since the sludge is stabilized, odor is not a serious problem. In warm weather, lime is applied over the surface of the sludge layer.

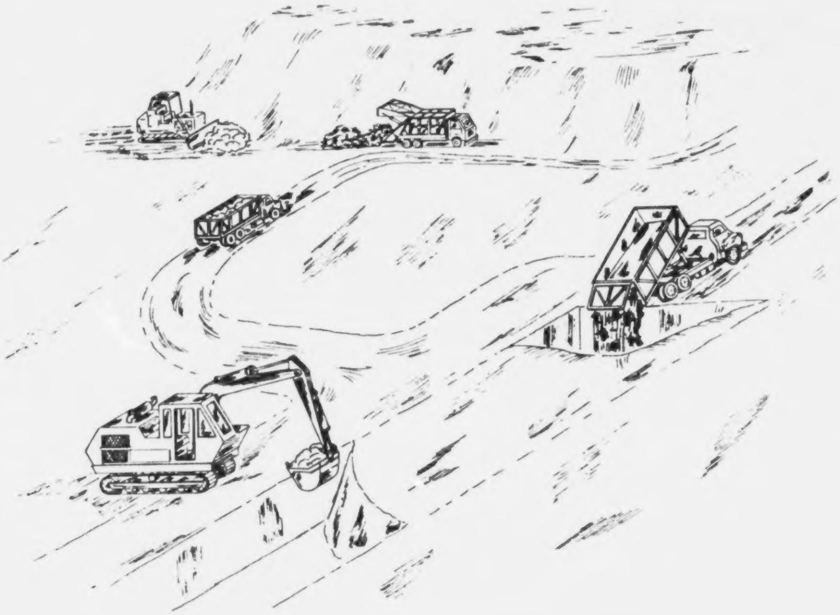


While the sludge unloading is occurring in one location, trench excavation and sludge covering are being conducted in other areas. Sludge-filled trenches are covered with soil taken from newly excavated trenches. The sludge-filled trench is covered carefully in order to prevent the displacement of sludge by the soil cover. Covering the sludge-filled trench in this manner produces rugged mounds 5 to 6 ft (1.5 to 1.8 m) high throughout the area. The trenches are then allowed to settle for several months before the area is regraded to a smooth surface.

FIGURE 6-2

WIDE TRENCH OPERATION AT REFUSE LANDFILL

This trench operation is located on a 100-acre (40-ha) refuse landfill site near Greenville, Michigan. A single wide trench 300 ft (90 m) long, 30 ft (9 m) wide, and 15 ft (4.6 m) deep is employed to dispose of approximately 25 yd^3 (19 m^3) of anaerobically digested and dewatered sludge each day. The trench is constructed using one excavator equipped with a 36 in. (91 cm) wide bucket. Dump trucks unload the 15% solids sludge at the edge of the trench, starting at one end and moving forward as the trench is filled.

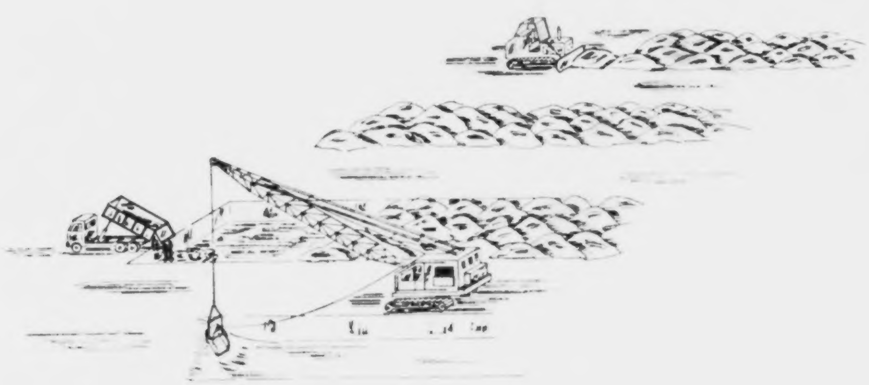


The trench filling operation takes approximately 6 to 8 months, in which time the sludge dewaters through the sandy soil. By the time the trench is totally filled, the old sludge at one end of the trench is dry enough to be removed by an excavator, mixed with soil, and applied as cover on the refuse landfill. This progression of sludge filling and subsequent removal enables the trenching operation to be confined to a small area. The sludge/soil mixture increases the organic content of the soil and enhances vegetative growth on completed fill areas at the refuse landfill. The sandy soil at the site drains well and hence the operation is effective even with the relatively high rainfall common in the area.

FIGURE 6-3

WIDE TRENCH OPERATION WITH DRAGLINE

A privately operated site near Cleveland, Ohio receives 450 wet tons (408 Mg) of sludge daily from four sources. Most of the sludge is digested and/or chemically treated, and averages 20% solids. Sludge is unloaded from haul vehicles directly into trenches. Because of its consistency, the sludge flows throughout the trench and spreads out evenly.

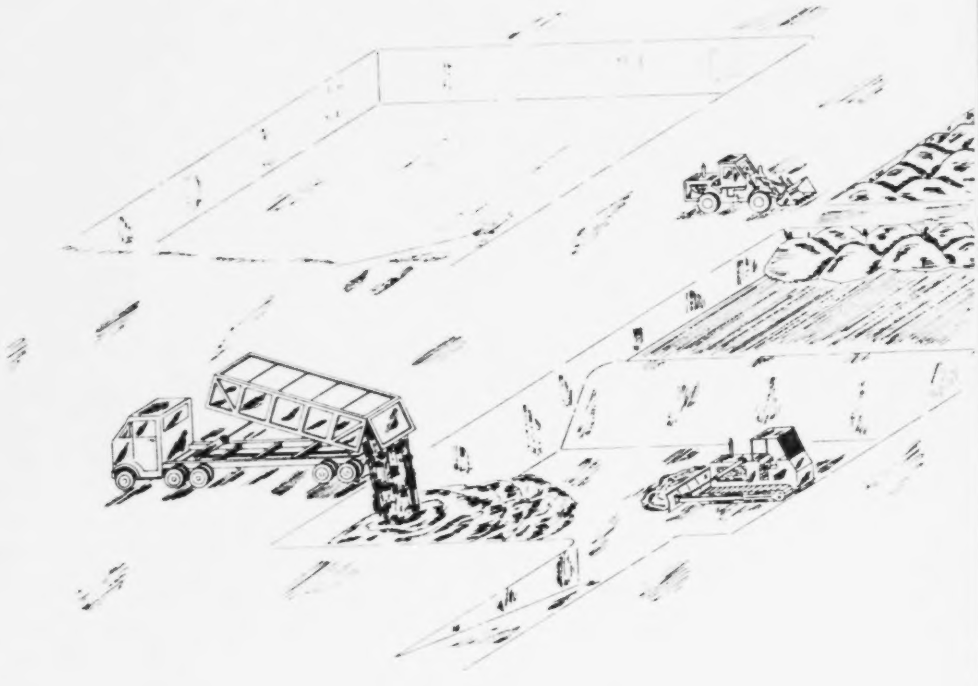


The trenches are excavated by a dragline with a 50 ft (15 m) boom and 4.5 yd^3 (3.4 m^3) bucket. They are 40 ft (12 m) wide, 700 ft (210 m) long, and 5 to 6 ft (1.5 to 1.8 m) deep. Sludge is deposited to a depth of 3 ft (0.9 m) and is then covered with 5 ft (1.5 m) of soil, resulting in a mound that ranges from 2 to 3 ft (0.6 to 0.9 m) above grade. Cover for sludge filled trenches is supplied by spoil material generated from excavation of the parallel trench. Because of the low solids content, the cover is applied by the dragline with the bucket initially at a minimum height. This ensures minimum displacement of the sludge by cover material. After the first layer of cover is applied, the dragline applies the remaining cover from a greater height. The trenches are allowed to settle before a bulldozer is used to final grade the area. Initial designs called for a wider trench but experience indicated that the dragline would have to be moved excessively. Accordingly, the width was reduced to 40 ft (12 m).

FIGURE 6-4

WIDE TRENCH OPERATION WITH INTERIOR DIKES

A privately operated sludge landfill in Cleveland, Ohio receives 250 wet tons (226 Mg) of sludge daily from several sources. The sludge is digested and/or chemically treated and has an average solids content of 20%. Trenches are 40 ft (12 m) deep and 700 ft (213 m) long. Dikes are placed at intervals within the trench to facilitate phased filling and covering. The dikes are placed at intervals that ensure frequent cover applications. Sludge is unloaded directly into trenches and spreads out evenly throughout the contained area. Two to 3 ft (0.6 to 0.9 m) of cover material is applied by front-end loaders and excavators excavating a parallel trench. Completed areas are regraded from 6 to 9 months after cover is applied and subsequently reseeded with grass.



6.2.2.1 Area Fill Mounds

Area fill mounds may be employed in a variety of topographies. Usually such operations are conducted on level ground. However, mound landfills are also well suited to construction against a hillside which can provide containment on one or more sides.

6.2.2.1.1 Site Preparation

The first step is to prepare the subgrade. Depending on design specifications this may include underdrains and/or liners for leachate collection. Due to the large amount of soil required for proper operation of area fill mounds, emphasis should be placed on securing sufficient soil material. Accordingly, the fill should be confined to a small area and proceed vertically to the maximum extent possible. This will reduce the areal extent of the landfill and consequently reduce erosion and silt-laden runoff from denuded areas, provided the slope does not become excessive.

The excavation can be carried out in phases to take advantage of soil differences. Any soil that has to be stockpiled for use as a sludge bulking agent should be placed in compacted, sloping piles. To keep the soil dry, piles may be covered with tarpaulins and the tarpaulins secured using old rubber tires. Wet soils, because they are not suitable for sludge bulking, should not be stockpiled. Soil that is stockpiled should be placed as close as possible to points of eventual use and access to stockpiles provided.

6.2.2.1.2 Sludge Unloading

The sludge may be unloaded either in the filling area or in the designated unloading and mixing area near the bulking agent stockpile. The unloading area should be clean and relatively level for safe passage of trucks. Haul vehicles should not drive over completed sludge filling areas.

6.2.2.1.3 Sludge Handling and Covering

Operational procedures should be provided to specify what soils are to be mixed with sludge, where they are to be obtained, and how they are to be mixed and/or placed over the sludge. The amount of material required for each function is determined by site design specifications which take into account soil and sludge characteristics. Preliminary trial and error tests to determine sludge/soil ratios that produce sludge with appropriate consistencies should be attempted during initial operations.

Construction of area fill mounds requires that the sludge/soil mixture be relatively stable. Sludge/soil mounds are generally applied in a series of lifts with each lift containing one level of mounds. When completed, the lift should be covered with a layer of soil sufficient to safely support on-site operating equipment.

Once the area is filled to the designated contours, the entire fill area should be covered with 3 to 5 ft (0.9 to 1.5 m) of soil material (preferably impermeable soil such as clay if it is available). The fill area should then be final graded to account for future settlement and promote drainage. A layer of topsoil up to 2 ft (0.6 m) may be used as final dressing and the area seeded with grass to prevent erosion.

6.2.2.2 Area Fill Layer

Area fill layers may also be employed in a variety of topographies. Layer operations consist of a series of sludge layers with interim and final cover applications.

6.2.2.2.1 Site Preparation

As with area fill mounds, the first step is to prepare the subgrade. Again, liners and/or subdrain systems may be utilized depending on hydrogeological conditions. Fill areas for layer operations should be nearly level. Although the soil requirements of such operations are less than those of area fill mounds, it may be necessary to import soil. In any case, soil stockpiles should be established, both for use as bulking agents and cover soils. Areas should be excavated only as they are used, to the maximum extent possible. This will reduce the amount of denuded area subject to erosion.

6.2.2.2.2 Sludge Unloading

Specific unloading and sludge/soil mixing areas may be maintained or sludge can be placed directly in the fill area. An effective method in layer operations is to maintain soil stockpiles on the fill area itself. Bulldozers then mix and layer the sludge in one operation. Again, storage areas should be located away from traffic.

6.2.2.2.3 Sludge Handling and Covering

In general, design specifications based on sludge characteristics will give some indication of the required amounts of bulking agent. Nevertheless, it is always advisable to conduct preliminary trial and error tests to determine bulking ratios appropriate for supporting equipment. The depth of interim and final cover can also be determined in this manner. Again, when the area has been filled to the contours established in the design, a final cover of 2 to 4 ft (0.6 to 1.2 m) should be applied and the area seeded. It will be necessary to regrade the site in 6 to 12 months, and possibly thereafter as the fill area settles and compacts.

6.2.2.3 Diked Containment

Diked containments are essentially aboveground wide trenches and, as such, use similar procedures and equipment. The design and construction of dikes, however, is more complex and is usually not warranted. Only in cases where high groundwater tables, bedrock and/or low solids, rule out more conventional methods is their expense justified.

6.2.2.3.1 Site Preparation

The first step in preparing the site for diked containment is to provide a suitable subgrade or a liner, if necessary. Next, soil should be imported from other areas if needed. This soil should be relatively impermeable. The dike base is then constructed maintaining design dimensions and slopes (generally from 2H:1V to 3H:1V for sideslopes). Succeeding layers are then applied and each layer compacted by passing equipment over it. Alternatively, the containment area may be constructed against one or more steep sideslopes. A ramp should be provided for unloading vehicles.

6.2.2.3.2 Sludge Unloading

Sludge may be unloaded from the top of the dike or in an area designated for sludge/soil mixing. Slopes and grades of access roads should be maintained to design specifications. Provisions should be made for inclement weather (e.g., stockpiled soil kept dry).

6.2.2.3.2 Sludge Handling and Covering

The containment area is filled with sludge in layers, usually with interim soil or gravel cover provided at predetermined heights. Draglines are frequently used to apply interim and final cover. The final cover should be 3 to 5 ft (0.9 to 1.5 m) thick. Ideally, this could consist of a relatively impermeable layer of clay about 1 to 3 ft (0.3 to 0.9 m) thick, followed by 2 ft (0.6 m) of topsoil [1]. It is usually necessary to reapply the final cover after initial settlement has occurred. If additional settlement causes depressions, the site will have to be regraded. The area should be seeded with a suitable vegetative cover.

6.2.2.4 Operational Schematics

The preceding information has been included to generally describe the operation of sludge-only area fills. Figures 6-5 through 6-8 illustrate specific area fill operations.

6.2.3 Codisposal

In codisposal operations, sludge is received at a landfill receiving typical municipal refuse. Two kinds of codisposal operations have been identified including (1) sludge/refuse mixture and (2) sludge/soil mixture. For sludge/refuse mixtures, sludge is mixed directly with refuse and landfilled at the working face. For sludge/soil mixtures, sludge is mixed with soil and used as cover over completed refuse fill areas. Chapters 3 and 5 should be consulted for specific design criteria.

6.2.3.1 Sludge/Refuse Mixture

Once sludge receipt has begun, every effort should be made to take full advantage of the absorptive capacity of the refuse. Consequently, the sludge should be mixed with the refuse as thoroughly as possible. One procedure employed calls for refuse to be dumped at the bottom of the working face, and subsequently pushed, spread, and compacted by equipment working up the working face. Under these circumstances, sludge can be handled in two alternative ways. The first way includes:

1. Dump the refuse at the bottom of the working face
2. Dump the sludge atop the refuse pile
3. Thoroughly mix the sludge and refuse
4. Push, spread, and compact the sludge/refuse mixture up the working face

FIGURE 6-5

AREA FILL MOUND OPERATION

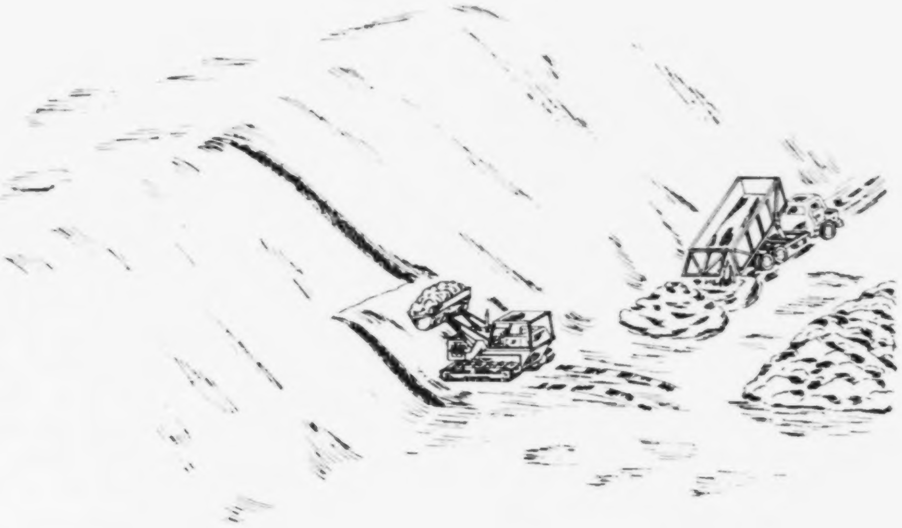
A site in Lewiston-Auburn, Maine receives 40 wet tons (36 Mg) per day of chemically treated sludge. The disposal site is an abandoned gravel pit with a clay liner and underdrains for leachate collection. Leachate collected at the site is conveyed to the treatment plant via a nearby sewer interceptor.

The sludge is unloaded onto a receiving and mixing pad constructed with gravel and crushed stone. A large covered pile of borrowed sand is located near this receiving area. Each 10 yd^3 (8 m^3) load of sludge is thoroughly mixed with 6 yd^3 (4.6 m^3) of fine sand. A loader then transports the sludge/sand material into the fill area and pushes and piles the material into 6 to 8 ft (1.8 to 2.4 m) high mounds. During wet weather, the mounds slump and they must be continuously piled and pushed by small track dozer. The 8 ft (2.4 m) high mounds form a lift that must be covered by 1 to 2 ft (0.3 to 0.6 m) of gravel to support equipment. Lifts are produced to complete the site, filling it to its original grade. The entire fill area will ultimately be covered with an impermeable layer of clay and graded to ensure proper drainage.

FIGURE 6-6

AREA FILL LAYER OPERATION

This area fill layer operation is located on 150 acres (61 ha). Approximately 40 yd^3 (30 m^3) of digested and dewatered sludge is brought to the site daily. The 25% solids sludge has a thin layer of lime applied to it and is then left uncovered to promote further dewatering. A track loader mixes the sludge with soil (a 3:1 soil to sludge ratio) obtained from a stockpile, and applies the material in 10 ft (3 m) wide, 3 ft (0.9 m) thick layers against a slope. Each layer receives 6 in. (15 cm) of interim cover. A progressive 3:1 slope is constructed from the layering operation.

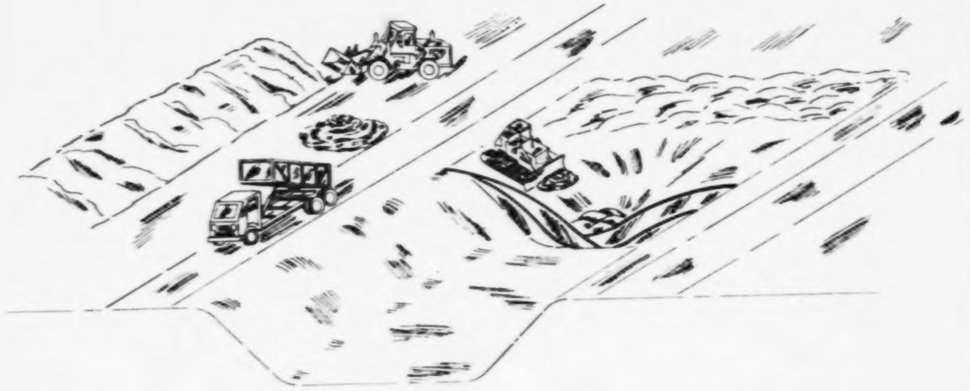


In wet weather, the track dozer loses traction and is unable to layer the sludge on the slope. For this reason, a separate wet weather area is maintained on relatively level ground near the entrance. The ground beneath the working face is sloped so that runoff is directed to one end of the area. From here the runoff is directed to a holding pond. A final soil cover of 3 ft (0.9 m) is applied on the completed slope and the area is seeded. If necessary, sludge is disced into the soil cover to enrich the soil prior to seeding.

FIGURE 6-7

AREA FILL LAYER OPERATION INSIDE TRENCH

A landfill at Frederick, Maryland receives 30 wet tons (27 Mg) per day of 23% solids sludge. Trenches 45 ft (14 m) wide, 20 ft (6 m) deep, and 200 ft (60 m) long are constructed with a scraper and track dozer. A minimum of 20 ft (6 m) of solid ground is maintained between trenches. Excavated material is stockpiled along one length of the trench, but set back at least 20 ft (6 m) from the excavation edge.

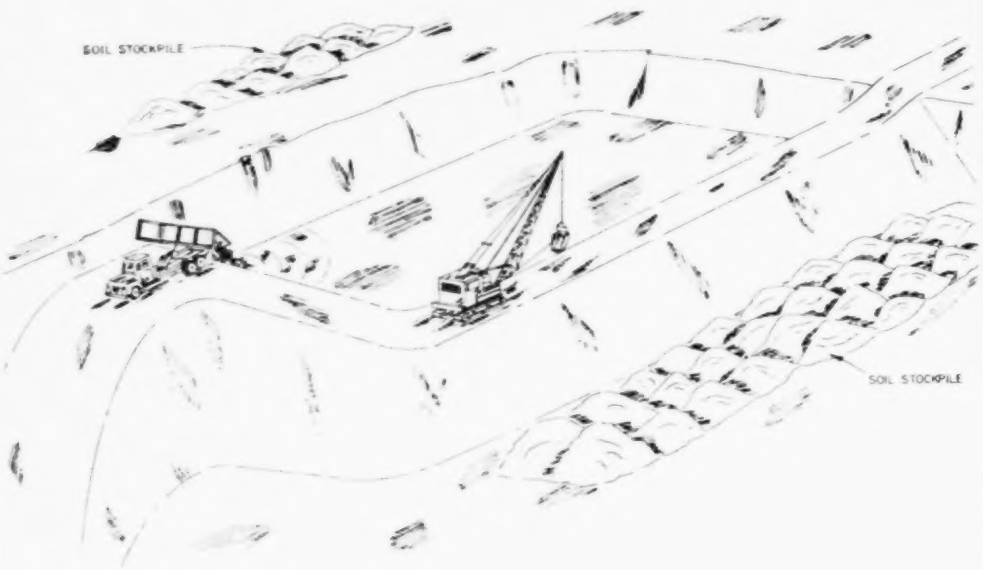


Sludge is unloaded along alternate sides of the trench depending on weather. When wet conditions prevail, the sludge is unloaded adjacent to the stockpile. When the weather is dry and operations of unloading vehicles and equipment are not hindered,the sludge is unloaded on the other side. After two loads have been dumped, a wheel loader mixes soil from the stockpile with the sludge at 1 or 2 parts soil to 1 part sludge. The sludge/soil mixture is then pushed downslope toward the center of the trench. The operation proceeds alternatively on each side of the trench. The sludge/soil mixture is covered daily with a thin lyer of 2 to 4 in. (5 to 10 cm) of soil. The trench is filled to within 2 ft (0.6 m) of the surface and allowed to settle. A 6 to 12 in. (15 to 30 cm) layer of clay is then applied, followed by about 2 ft (0.6 m) of top soil. The top soil is stockpiled separately on-site as the trenches are excavated. The design originally called for a narrower 30 ft (9 m) wide trench, but experience indicated that the wider trench was more efficient in terms of land use and costs.

FIGURE 6-8

DIKED CONTAINMENT OPERATION

This landfill operation uses a diked containment design for sludge disposal. The municipality had investigated other landfilling methods but decided to use a diked containment due to the shallow groundwater and bedrock in the area and the relatively low solids of the sludge. Containment areas are constructed into the side of a hill. Soil material is generated in part by excavating the containment area with a scraper and a track dozer. This material is mounded and compacted by the dozer. Additional soil is imported as necessary from other areas for completing the dikes and for cover soil stockpiles. When completed, individual diked containment areas are 100 ft (30 m) long, 40 ft (12 m) wide, and 30 ft (9 m) high. A leachate control system consisting of a clay liner and leachate collection pipes is then installed on the floor of the diked containment area.



Each day 200 wet tons (181 Mg) of digested, dewatered sludge is hauled to the site in large open-top dump trucks. The 20% solids sludge is dumped directly into the diked containment area. Due to its liquid nature, individual sludge piles slump considerably and spread out in the diked containment area. After the sludge reaches a height of 5 ft (1.5 m), 2 ft (6 m) of interim cover material is applied atop the sludge by a dragline. Additional interim cover is applied over the second lift when the sludge reaches a height of 12 ft (3.7 m). A final 5 ft (1.5 m) layer of final cover is applied over the sludge when it accumulates to within 3 ft (0.9 m) of grade.

The second method can be accomplished in the following way:

1. Dump the refuse at the bottom of the working face
2. Push, spread, and compact the refuse up the working face
3. Dump the sludge at the top of the working face
4. Push the sludge down the working face, spreading it evenly across the refuse

If small quantities of sludge are received at refuse landfills (i.e., less than 5%) it may be desirable to confine sludge dumping to a selected location on the working face. This approach is useful in landfills that are sufficiently large to ensure that refuse dumping proceeds simultaneously along a wide working face.

Precautions should be taken to contain any sludge which escapes from the working face. This may be particularly needed for a sludge with a low solids content. Containment can be achieved either by (1) landfilling the sludge in a small depression or (2) constructing a refuse or soil berm at the bottom of the working face.

Other factors to be considered for refuse landfills receiving sludge include increased odors and the possibility of a small increase in leachate generation. Appropriate steps can be taken to control odors including more frequent application of cover and spot addition of lime.

6.2.3.2 Sludge/Soil Mixture

Another option for handling sludge at refuse landfills is mixing the sludge with soil and then applying the mixture as cover material over refuse-filled areas. Although this technically is not sludge landfilling, it is a viable alternative, is particularly useful in promoting vegetative growth in completed fill areas, and is performed at numerous refuse landfills.

The application of this sludge/soil operation may proceed follows:

1. Spread sludge as received uniformly over the ground surface in a 3 to 6 in. (8 to 15 cm) thickness in an area designated for this purpose.

2. Disc the sludge into the soil.

3. Spread lime or masking agent over the sludge/soil mixture for odor control if necessary.

4. After a period ranging from 1 to 8 weeks time (depending on rainfall and climate) scrape up the sludge/soil mixture and spread it over completed fill areas where vegetative growth has been slow to take root.

6.2.3.3 Operational Schematics

The preceding information has been included to generally describe the operation of codisposal sites. Figures 6-9 through 6-11 illustrate specific codisposal operations.

6.3 General Operational Procedures

Operational factors that are generally applicable to all sludge landfilling methods include:

1. Environmental control practices
2. Inclement weather practices
3. Hours of operation
4. Special wastes

6.3.1 Environmental Control Practices

In many cases, environmental controls must be designed and constructed to lessen the environmental effects of sludge landfills. Maintaining these controls is necessary to the landfill operation. Common sense control practices will also help ensure an environmentally sound disposal operation. These environmental control practices are described in the following sections and outlined in Table 6-1.

6.3.1.1 Spillage

Enroute and on-site spillage of sludge must be cleaned up as soon as possible. Haul vehicles enroute to the disposal site should report even small spills to the operation supervisor, so emergency clean-up crews can take prompt action. On-site spills should be controlled as much as possible. It is a good policy to have lime on hand at all sludge disposal operations for spot application to spills if prompt clean-up is not

FIGURE 6-9

SLUDGE/REFUSE MIXTURE OPERATION

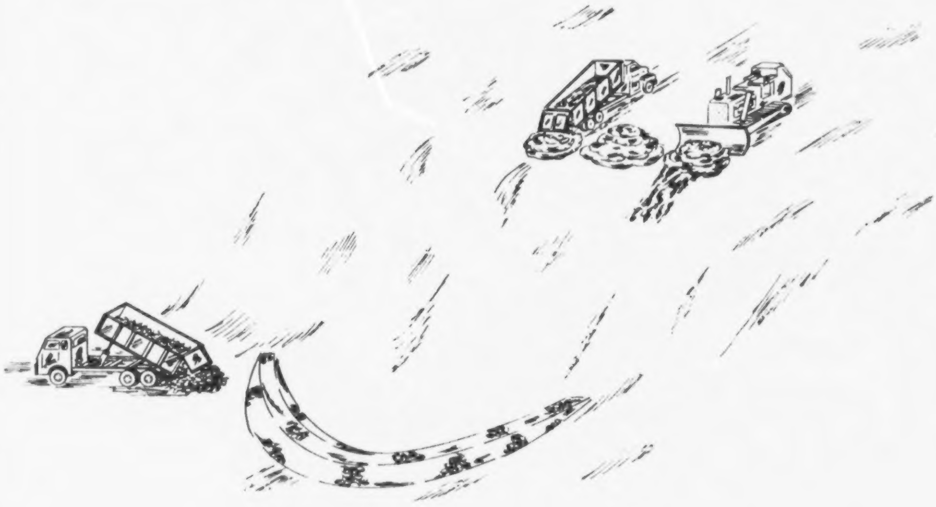
A site near Pittsburgh, Pennsylvania receives 100 wet tons (91 Mg) per day of 22% solids sludge. Two or three confined areas at the operating face are designated for sludge disposal. A layer of refuse is spread on the ground at the toe of the working face and the driver of the sludge haul vehicle directed to unload the sludge on top of the refuse so that the sludge is absorbed by the refuse. Generally, a few hours are allowed to permit the sludge to be absorbed by the refuse. More refuse is then piled on the sludge and a bulldozer mixes the sludge with the refuse at a ratio of approximately four parts refuse to one part sludge. Any ratio less than this has been found to cause soft spots in the fill area and create operational problems. The mixture is then pushed up the working face with bulldozers and compacted. An interim soil cover is applied at the end of each working day.

The timing of sludge deliveries is critical since there must be sufficient refuse available for operations to proceed. Accordingly, sludge deliveries are timed to coincide with refuse deliveries, which occur in the morning and early afternoon. The site encounters problems in wet weather. The 4:1 refuse mixture is found to be inadequate when the refuse is wet. The usual solution has been to increase refuse quantities. During warm weather the site experiences some odor problems. Masking agents are used when odors are a problem.

FIGURE 6-10

SLUDGE/REFUSE MIXTURE WITH DIKES

A codisposal site at Stafford, New Jersey, receives about 100 wet tons (91 Mg) of 17% solids sludge per day at specified locations on the working face. The sludge is deposited at the top of the slope and allowed to flow down the face into a refuse berm that is constructed at the toe of the face. The ratio of refuse to sludge is generally about 4 to 5 parts refuse to one part sludge. At the end of the day, the refuse is mixed with the sludge and pushed up the working face. Subsequently the mixture is compacted and cover applied. At times the operation has had difficulty containing the sludge during mixing operations, but by maintaining suitable ratios, the problem has been alleviated.



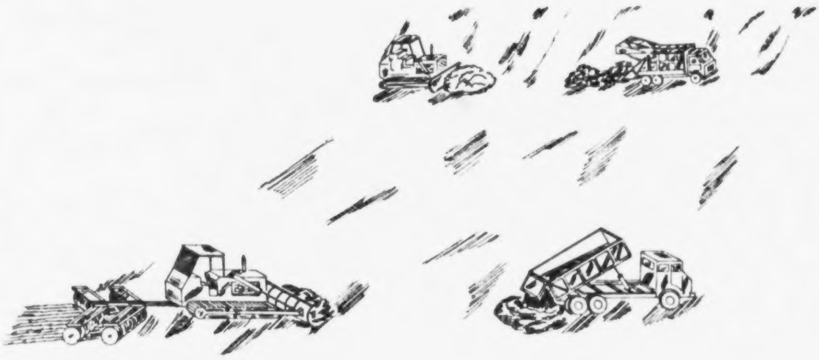
This technique enables operators to store refuse, which arrives at the site in the morning and early afternoon, and coordinate mixing operations with the sludge, which arrives continuously during the working day. Vegetation has been slow to take root in completed fill areas because the soil is sandy and has a low organic content. As a result plans are now underway to disc sludge into the soil prior to applying final cover.

The site is on a coastal plain and consequently has a milder climate than areas in similar latitudes. As a result, the site has not had problems with winter operations. However, during heavy rains the refuse dikes can become water logged, thus reducing the absorptive capacity of refuse.

FIGURE 6-11

SLUDGE/SOIL MIXTURE

A codisposal site near Washington, D.C. uses a sludge/soil mixture as final cover for completed fill areas. The site receives digested, dewatered sludge averaging 22% solids from 4 treatment plants. Sludge makes up about 10% of the total waste received at the site. The sludge is dumped in designated areas, spread evenly over the area in a thin layer, and thoroughly mixed with the soil using a discing apparatus. Approximately one week later, the sludge-soil mixture is scraped up and a masking agent added. It is then applied over completed areas as a soil enrichener. The mixture is generally 1 part sludge to 1 part soil. It was found that the mixture worked well in enhancing vegetative growth.



The site encounters some problems, with the operation particularly during winter operations when the soil is frozen and discing is difficult. At these times an alternative procedure, sludge/refuse codisposal, is generally used. Other problems that the site has encountered are mild odor problems. This is handled by applying masking agents.

A stream bisects the site and consequently runoff is carefully controlled. The stream is culverted and runoff is directed to siltation ponds so that discharge to the stream can be controlled.

TABLE 6-1
ENVIRONMENTAL CONTROL PRACTICES

Environmental Problems	Safety Program	Maintain Washrooms for Personnel	Training of New Personnel	Use Safety Clamps on Truck Tailgates	Maintain Road Markings and Trench Barriers	Maintain Fencing	Apply Insecticide	Maintain Buffer Areas and Grass	Proper Equipment Maintenance	Spray Water/Oil/Liquid Asphalt	Truck Wash Pad (to clean trucks)	Maintain Grass Waterways, Diversion Ditches, Rip Rap	Final Grading of Disturbed Areas	Revegetation of Disturbed Areas	Chemical Masking Agent	Lime on Site	Workers Supplied with Aerators	Cover Sludge Daily	Water Diverted Away From Site
Spillage			X	X	X				X							X			
Siltation and Erosion			X					X				X	X	X					X
Mud			X					X		X	X	X		X					X
Dust			X					X		X	X			X			X		
Vectors			X				X									X		X	
Odors			X					X			X				X	X	X	X	
Noise			X					X	X										
Aesthetics			X			X		X				X	X	X				X	
Health		X	X				X									X	X	X	
Safety	X		X	X	X	X			X							X	X	X	

feasible. The use of haul vehicles with baffles on them has been used effectively to limit spills.

6.3.1.2 Siltation and Erosion

The presence of silt-laden runoff from the site is often the result of improper grading. Grades of 2 to 5% should be maintained where feasible to promote overland surface drainage, while minimizing flow velocities. Denuded areas should be kept to a minimum during site operation. Ongoing construction and maintenance of sediment control devices (e.g., grass waterways, diversion ditches, rip-rap, sediment basins) are critical for an environmentally sound operation. During site completion, proper final grading, dressing, and seeding prevent long-term erosion and siltation problems.

6.3.1.3 Mud

Mud is usually caused by improper drainage but can be a problem at any site during heavy rains or spring thaws. To minimize the effect of mud on operations, access roads should be constructed of gravel. If practical, a wash pad should be located near the exit gate to clean mud from transport vehicles.

6.3.1.4 Dust

Dust is usually caused by wind or the movements of haul vehicles and equipment. To minimize dust, access roads should be graveled. Also, areas that are covered with interim or final soil cover should be vegetated as soon after their completion as possible. As an alternative, water can be applied to dusty roads.

6.3.1.5 Vectors

Vectors at sludge landfills include flies and mosquitos. Flies can be best controlled by placing adequate compacted cover soil as frequently as possible. Studies have shown that a daily cover consisting of 6 in. (1.3 cm) of compacted low-clay content soil will prevent fly emergence. However, even under the best of conditions, a sludge landfill should have a regular inspection and fly control program. Local controls can best dictate the specifics of any such program. Mosquito control is best obtained by preventing development of stagnant water bodies anywhere on the site. Continuous grading to fill low spots is essential.

6.3.1.6 Odors

Odors can be a serious problem at a sludge landfill unless preventive steps are taken. The sludge should be covered as frequently as necessary to minimize odor problems. Lime or chemical masking agents can be applied to reduce odor problems. An effective means of reducing odors is to limit storage of the sludge. Ideally, storage of sludge should be accomplished at the wastewater treatment plant.

6.3.1.7 Noise

Noise sources at sludge landfills include operating equipment and haul vehicles. Generally, the noise is similar to that generated by any heavy construction activity, and is confined to the site and the streets used to bring sludge to the site. To minimize the effect, every effort should be made to route traffic through the least populated areas. Further, the site can be isolated so that the noise cannot carry to nearby neighborhoods. The use of earthen berms and trees as noise barriers can be very effective. On the site, noise protection for employees will be governed by existing Occupational Safety and Health Act (OSHA) standards.

6.3.1.8 Aesthetics

To make the sludge landfill acceptable, every attempt should be made to keep the site compatible with its surroundings. During site preparation, it is important to leave as many trees as possible to form a visual barrier. Earthen berms can be similarly used. The use of architectural effects at the receiving area, the planting of trees along the property line, and confining dumping to designated areas will assist in the development of a sound operation. Additionally, every attempt should be made to minimize the size of the working area.

6.3.1.9 Health

Although there is a possibility that pathogens will be present in sludge, particularly if undigested, no health problems have been reported by site operators. Nevertheless, personnel should use caution when transporting, handling, and covering sludge. Washing facilities should be located on or near the disposal site for use in case of bodily contact with sludge.

6.3.1.10 Safety

As with any construction activity, safety methods must be implemented in accordance with OSHA guidelines. Work areas and access roads must be well marked to avoid on-site vehicle mishaps.

6.3.2 Inclement Weather Practices

Prolonged periods of rainy weather or freezing temperatures can impede routine operation of a sludge landfill. Anticipating the operational problems and addressing contingency operations in the operation plan will promote efficient operations. A listing of potential inclement weather problems and solutions has been included in Table 6-2.

6.3.3 Hours of Operation

Hours of operation should coincide with hours of sludge receipt. In this way, personnel and equipment are available to direct trucks to the proper unloading location; assist if trucks become mired in sludge or mud; and/or cover the sludge quickly to minimize odors. If the operation plan calls for daily covering of sludge, hours of operation should continue at least 1/2 hr past the hours of sludge receipt to allow for cleanup activities. Sludge deliveries after hours at the landfill should be discouraged.

6.3.4 Special Wastes

Municipal sludge landfills will generally receive grit, skimmings, screenings, and ash periodically. In most cases, handling and landfilling procedures are similar to those employed for sludge, but there are some important exceptions. Grit, screenings, and skimmings, because of their high organic content, are frequently sources of odor. Consequently, landfills may charge a higher fee and will usually not stockpile these wastes. Delivery of grit, screenings, and skimmings should be coordinated with active operating hours to assure that they can be processed. Ash, on the other hand, can be stored but should be kept dry if possible. If ash composition a significant portion of the waste disposed, then application rates should be lowered because of the relatively higher heavy metal concentrations. A further discussion of the characteristics and comparison of ash is presented in Chapter 3, Sludge Characteristics and Landfilling Methods.

TABLE 6-2

INCLEMENT WEATHER PROBLEMS AND SOLUTIONS

Inclement Weather Conditions	Sludge Loading and Transport	Site Preparation	Sludge Unloading	Sludge Handling and Covering
Wet	Problem: If hauling great distances, wet weather conditions may increase liquid content of sludge. Solution: Cover transport vehicle.	Problem: Maneuverability of equipment hindered in mud. Solution: Plan to move operation to an accessible working area. Problem: Depressions accumulate water, may draw flies, mosquitos. Solution: Grade area to promote surface runoff. Use insecticides only when necessary.	Problem: Maneuverability of transport vehicles hindered in mud. Solution: Place sand or gravel in areas to improve traction. Increase depth of road material. Problem: Instability of trench walls may cause collapse while unloading. Solution: Have transport vehicle dump at trench lip and push sludge into trench with equipment. Problem: Mud and sludge accumulates on haul vehicles and equipment. Solution: A washing pad at the receiving area will clean vehicles.	Problem: When mixing sludge with refuse or soil, need more mixing material. Solution: Ensure sufficient supply of refuse or soil material. Problem: Ponded water collecting in trenches. Solution: Use potable pump to remove excess water.
Cold	Problem: Sludge freezes in haul vehicles. Solution: Line trucks with salt water, straw, sand or oil. Do not allow prolonged exposure to cold (park in garage). Use exhaust to heat the trailer.	Problem: Deep penetration of frost in trench areas. Solution: - Construct trenches during good weather and save for cold months. - Do not remove snow (acts as insulator) or allow vehicles to ride on trenching areas (causes frost to penetrate deeper into the ground). - Hydraulic rippers or jackhammers are to be used as a last resort.	Problem: Tailgates freeze. Solution: (1) Spray ethylene glycol on frozen parts. (2) use exhaust to heat frozen parts. Problem: Previously (fall season) muddy roads form severe ruts and chuck holes. Solution: Regrade and build before winter freeze.	Problem: Deep penetration of frost in cover supply areas. Solution: Accumulate stockpile in good weather. Ensure supply of cover material; insulate piles with tarpaulin or hay. Problem: Equipment freeze-up. Solution: Trucks or crawlers should be well cleaned of sludge and soil.

Another factor that should be anticipated is the fluctuations in treatment plant operations and the consequent variation in the characteristics of the sludge delivered. Occasionally, excessively wet or malodorous loads may be received. Operational procedures should be established for these loads. Typically, procedures range from outright refusal of the load to maintenance of special areas or soil stockpiles to handle substandard loads.

6.4 Equipment and Personnel

A wide variety of equipment is utilized at sludge landfills. Equipment selected depends largely on (1) landfilling method and design dimensions employed and (2) quantity of sludge received.

Since equipment represents a large capital investment and accounts for a large portion of the operating cost, equipment selection should be based on a careful evaluation of the functions to be performed and the cost and ability of various machines to meet these needs. Contingency equipment for downtime and maintenance may be necessary at larger sites. These may be rented or borrowed from other municipal functions.

Table 6-3 provides guidance on the suitability of equipment to perform selected sludge landfilling tasks. Table 6-4 provides typical equipment selections for seven operational schemes. These matrices are meant to give general guidance on the selection of sludge landfill equipment. However, it should be noted that general recommendations on equipment selection can be misleading. In all cases, final selection should be based on site-specific considerations. Figures 6-12 through 6-15 illustrate typical equipment used at sludge landfills.

The importance of employing qualified and well-trained personnel at sludge landfills cannot be overstated. Qualified personnel often make the difference between a well-organized, efficient operation and a poor operation.

Typical positions required at sludge landfills include the following:

1. Equipment Operator. At many sludge landfills, these will be the only personnel required. Tasks performed are mostly those of equipment operation. However, other tasks include routine equipment maintenance and directing sludge unloading operations.

TABLE 6-3

EQUIPMENT PERFORMANCE CHARACTERISTICS

	TRENCH				AREA FILL													CODISPOSAL					
	Narrow Trench		Wide Trench		Mound					Layer					Diked Contain-ment			Sludge/ Refuse		Sludge/ Soil			
Equipment Name	Trench Construction	Covering	Trench Construction	Covering	Soil Hauling	Mixing	Sludge Hauling	Mounding	Covering	Soil Hauling	Mixing	Sludge Hauling	Layering	Covering	Soil Hauling	Dike Construction	Covering	Spreading	Covering	Sludge Spreading	Mixing	Hauling	Covering
Trenching Machine	G	G	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Backhoe with Loader	G	G	-	-	F	F	F	G	F	F	F	F	-	-	F	-	-	-	-	-	-	-	-
Excavator	G	F	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Track Loader	-	G	G	F	F	G	F	G	G	F	G	F	F	F	F	F	-	F	F	F	-	G	F
Wheel Loader	-	G	F	-	G	F	G	F	F	G	G	G	-	-	G	F	-	-	-	-	-	F	F
Track Dozer[a]	-	G	G	G	-	G	-	F	G	-	G	-	G	G	-	G	G	G	G	G	F	-	G
Scraper	-	-	G	-	G	-	F	-	-	G	-	F	G	G	G	G	-	-	F	-	-	F	F
Dragline	G	G	G	G	-	-	-	-	G	-	-	-	-	-	-	-	G	-	-	-	-	-	-
Grader	-	-	-	-	-	-	-	-	-	-	-	-	G	G	-	-	-	-	-	F	-	-	-
Tractor with Disc	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	G	-	-

LEGEND

G - Good. Fully capable of performing function listed. Equipment could be selected solely on basis of function listed.

F = Fair. Marginally capable of performing function listed. Equipment should be selected on basis of full capabilities in other function.

- = Not applicable. Cannot be used for function listed

a Caterpillar D-6 generally is the largest track dozer appropriate for a sludge landfill.

TABLE 6-4

TYPICAL EQUIPMENT SELECTION SCHEMES

	Trench Method										Area Fill Method															Co-disposal Method[f]									
	Narrow Trench					Wide Trench					Mound					Layer					Diked Containment					Sludge/Refuse					Sludge/Soil				
Equipment	1[a]	2[b]	3[c]	4[d]	5[e]	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
Trenching Machine				1	2																														
Backhoe with Loader	1	1		1*	1							1*	1*	1*	1																				
Excavator			1																																
Track Loader						1	1*	1		1*	1	1	1	1	1															1			1*	1*	2*
Wheel Loader														1	1					1*															
Track Dozer		1*	1	1	2*		1*	1	1	2*			1*	1	1	1	1	1	2*	2	1	1*	1*	1	2*			1*	1	1					
Scraper									1*	1			1*	1*	1		1*	1*	1*	1			1*	1	1										
Dragline																						1	1	1	1										
Grader																																		1*	1
Tractor with Disc																															1	1	1*	2*	2
Total	1	2	2	3	5	1	2	2	2	4	1	2	4	5	5	1	2	2	3	4	1	2	3	3	4	-	-	1	1	2	1	1	2	4	5

a Scheme 1 - 10 wet tons/day

b Scheme 2 - 50 wet tons/day

c Scheme 3 - 100 wet tons/day

d Scheme 4 - 250 wet tons/day

e Scheme 5 - 500 wet tons/day

f Additional equipment only

* May not receive 100% utilization

FIGURE 6-12
SCRAPER

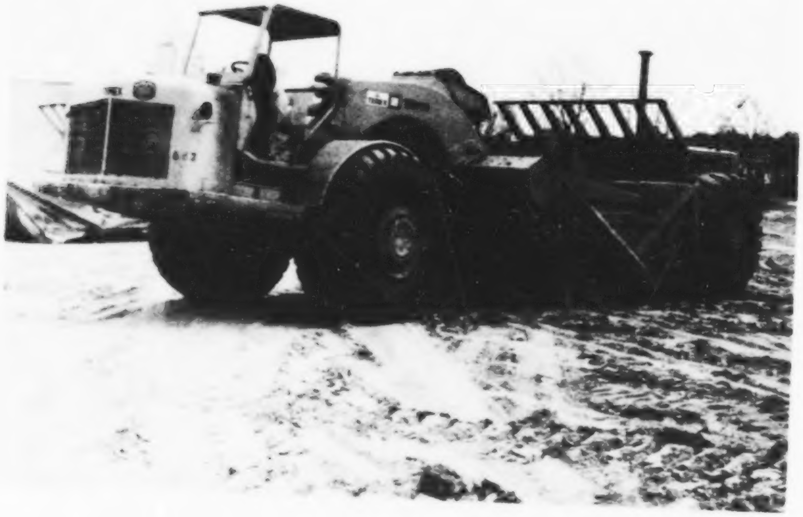


FIGURE 6-13
BACKHOE WITH LOADER

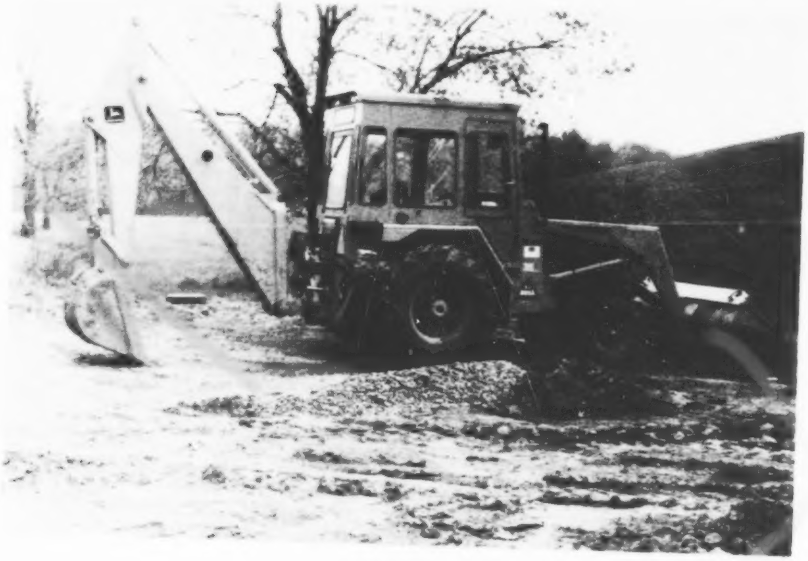
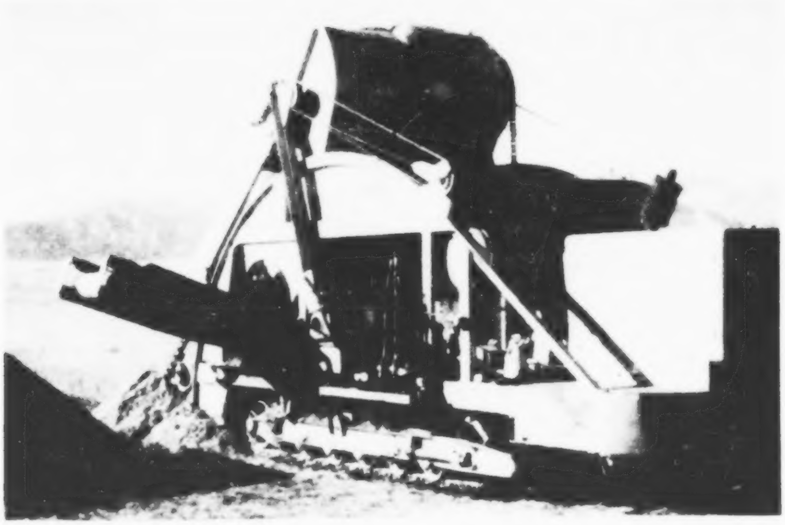


FIGURE 6-14
LOAD LUGGER

FIGURE 6-15
TRENCHING MACHINE



2. Superintendent/Foreman/Supervisor. This position involves overseeing all aspects of the landfill operation, including keeping cost records, processing personnel grievances, and managing the operation. Also, this person often serves other functions, such as operating equipment.

3. Mechanic. Major equipment maintenance and repair is performed by qualified mechanics. Mechanics or maintenance teams seldom are needed full-time on site. They may come to the site as repairs are required.

4. Laborer. Larger sites may need one person to maintain control devices for leachate collection and treatment, odor control, and mud and dust control. He also can ensure that fencing and access roads are properly maintained.

6.5 Reference

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CHAPTER 7

MONITORING

7.1 Introduction

Environmental and legal sensitivity to potential water contamination necessitates the monitoring of sludge landfills. The purpose of monitoring may include establishing baseline data, detecting contamination, satisfying regulatory constraints, securing data for use in litigation, or conducting research projects. Despite the particular objective of any monitoring network, site monitoring will continue to constitute an increasingly integral component of any sludge landfill operation. Ideally, monitoring should be used to confirm the predictions and judgements made during the project development and design stage with respect to protecting the ecosystem. Monitoring at a sludge landfill usually addresses groundwater and/or surface water and occasionally gas migration. Monitoring of surface water and gases are not required if there are no surface water bodies or structures nearby.

7.2 Groundwater Monitoring

A series of evaluations are usually made prior to implementation of groundwater monitoring. The items to be evaluated include:

1. Pertinent conditions of the hydrologic framework
2. Characteristics of the sludge received
3. Man-induced and geologic features affecting the movement of leachate.
4. Groundwater use

7.2.1 Hydrologic Conditions

In a preliminary form, the following items require determination for hydrologic characterization at a site:

1. Climatological setting
2. Groundwater delineation such as depth, flow patterns, fluctuations, etc.

FIGURE 7-1

LANDFILL WATER BALANCE SIMPLIFIED

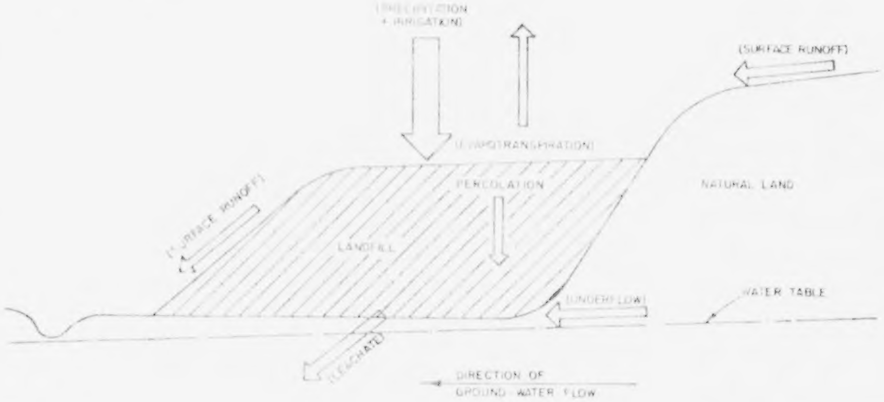


Figure 7-1 is a simplified hydrologic cycle illustrating these factors.

Examination of these hydrologic components should be conducted to a level of detail commensurate with the goals of the proposed monitoring system.

7.2.1.1 Climate

Information of interest includes:

1. Historical rainfall intensity data for a 24-hr period
2. Maximum monthly and yearly precipitation data
3. Temperature, evapo-transpiration, and wind information

These records can usually be obtained from a nearby National Oceanic and Atmospheric Administration (NOAA) weather station. Estimates of such data may be necessary if sources for existing data are unavailable.

7.2.1.2 Groundwater Conditions

An examination of the groundwater system includes the following:

1. Groundwater streamline patterns
2. Depth of groundwater
3. Groundwater quality and uses
4. Seasonal fluctuations in depth

Prior to any field investigation a number of information sources should be contacted to define the regional and local hydrologic regime. Regional sources include federal, state, and private publications, maps, aerial photographs, and remote sensing imagery. Useful local information can be obtained from consultants, well drillers, city or county agencies, nearby universities, and adjacent land owners. These other sources usually provide data for both regional and site specific conditions.

If existing background data does not provide sufficient information on groundwater conditions, a relatively inexpensive method utilizing three wells can be used to supplement this knowledge. The usual process involves installing three well points below the groundwater table in a triangular arrangement surrounding sludge landfills. Absolute elevations of each well are surveyed and recorded. Water level measurements in these wells are made periodically, and water level contours developed. This provides information on streamline (flow) patterns, groundwater depths, and, if monitored throughout the course of a year, data on seasonal groundwater fluctuations. Background groundwater quality levels should also be identified, either by reviewing available information or by analyzing water samples from nearby wells upstream from the sludge landfill.

7.2.2 Sludge Characteristics

Ideally, the sludge should be thoroughly characterized prior to landfilling. The viability of its chemical and physical properties should also be determined. Characteristics of primary interest are the solids content, heavy metals (e.g., lead, zinc, cadmium), pH, and nitrates. In addition, organics and cyanides are important constituents that should be identified. Constituents that are present at relatively high concentrations and/or are highly soluble in water should be included in the groundwater analysis since it is likely that these constituents would be present in the leachate.

7.2.3 Man-Induced and Geologic Features

Other factors which can influence the groundwater flow patterns or contamination levels are wells, subsurface barriers, geologic conditions, or nearby possible waste point sources. These factors could manifest themselves in a variety of features such as fractured bedrock, abandoned wells, highly porous soil horizons, septic tanks, etc. Depending upon the intensity of the monitoring, either a background geologic report (if available) or an on-site investigation is needed. Field geologic examinations should include all geologic formations down to and including the aquifer.

7.2.4 Field Installations

Proper location and installation of monitoring wells are essential to a monitoring program. A number of excellent references should be reviewed for determining which combinations best suit a particular monitoring program [1][2][3][4][5][6][7]. Generally, once the hydrogeological setting and the waste characteristics have been defined, it is possible to develop a site specific monitoring plan [1][8][9].

In field installations, particular attention should be given to two major items to ensure optimum benefit from each sampling point. These items are proper vertical and horizontal placement and the selection of sampling devices best suited to the particular goals of the study. The locations and depths at which the monitoring wells or devices are placed should be based on the information obtained during the site investigation. Monitoring wells should be placed in those areas representing optimum pathways for contaminants migrating from the sludge landfill. Wells should be installed 10 ft (3 m) or deeper into the groundwater. Knowing (1) the age of the sludge landfill, (2) approximate permeability values in the zone of aeration, and (3) directions and velocities of groundwater flow, rough estimates can be derived as to the maximum aerial extent of contaminant migration. This approximation can provide a zone of highest probability for leachate detection.

7.2.4.1 Characteristics of the Aquifer

Some of the site-specific characteristics that will influence the placement of monitoring wells are:

1. Geologic nature of the aquifer
2. Characteristics of the potential leachate
3. Groundwater flow rates

For the purposes of monitoring, it is useful to categorize an aquifer according to the nature of its porosity. Porosity, in turn, may be intergranular, fracture induced, or solutional. Unconsolidated alluvium and consolidated sedimentary rock usually exhibit flow via intergranular porosities; crystalline rocks exhibit movement via fractures, and limestone, marble, and other soluble rocks exhibit movement via solutional channels.

The rate of groundwater flow through some sedimentary or alluvial aquifers may be much slower (typically 4.9 ft/yr (1.5 m/yr)) in clay or compacted shales than in solutional or fractured aquifers (up to 16 ft/day (5 m/day)). The distance at which monitoring stations should be located is determined in part by the rate of groundwater flow: a greater down-gradient distance is required for rapid flows, a shorter distance for slower rates.

The movement of groundwater through sedimentary aquifers is generally isotropic, determined chiefly by the gradient. Flow through fractured or solutional rock, on the other hand, exhibits preferential channels of movement. Again, the placement of monitoring wells should accommodate these differences by locating monitoring wells along major fractures or solution channels where appropriate.

The depth to which a well should penetrate the aquifer is partly a function of the leachate. Since groundwater exhibits laminar flow in most aquifers, it does not generally disperse itself through the aquifer, rather it moves in a cohesive plume. This plume may "float" atop the water table or "sink" to the bottom, depending on the specific gravity of the leachate. Knowing the nature of the potential contaminants will enable landfill operators to predict the movement of the plume and consequently the extent of penetration required for monitoring wells.

Other characteristics of the aquifer that should be ascertained are the presence of artesian pressure, presence of multiple aquifers separated by aquitards or aquicludes, and the location and orientation of faults and major fractures through the aquifer. Perched water tables should also be located and their relationship to the primary aquifer ascertained.

7.2.4.2 Sampling and Monitoring Program

The number of wells required at the sludge disposal site is highly site-specific. A hydrogeologist should be consulted to assist in determining the number of wells required and their locations.

Generally the following types of wells are needed:

- Background wells - located upstream, not affected or contaminated by landfill leachate
- Downstream wells - Located a few hundred feet downstream from the landfill, used to detect leachate migration; others located immediately downstream of the fill area in the zone of maximum leachate concentration

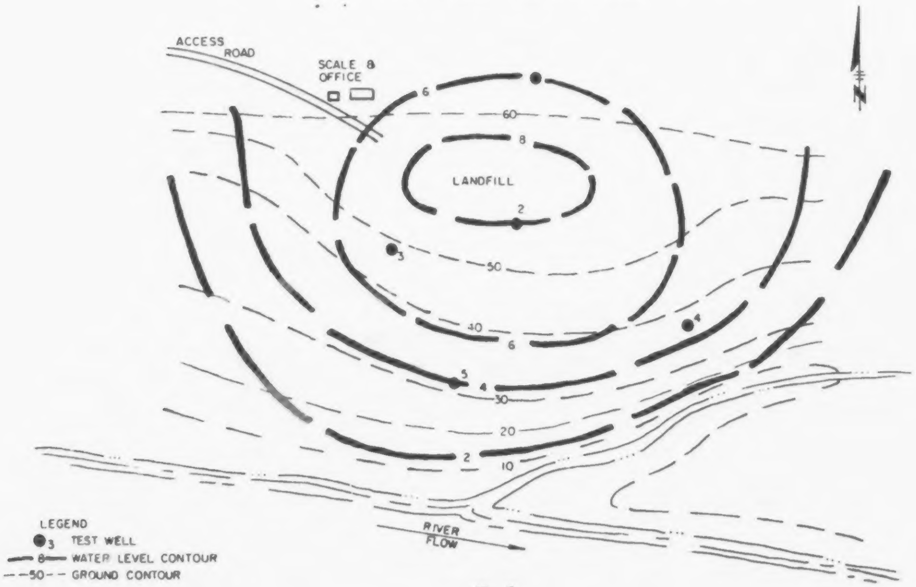
Care must be taken to ensure that exterior sources or seasonal fluctuations of the streamlines do not interfere with any of these wells.

Often these monitoring wells or at least several of the wells will have been installed during the site selection and/or design investigations. In fact, it is desirable to start monitoring the wells 6 months to a year before any sludge filling to establish background groundwater quality including any seasonal fluctuations, to determine positively whether the landfill is affecting the water quality.

An actual monitoring network, established to monitor an existing landfill, is presented in Figure 7-2. A hydrogeologist was consulted and assisted in locating the wells. After a visual inspection of the site, the hydrogeologist recommended that resistivity surveys be conducted.

FIGURE 7-2

WATER TABLE AND LAND SURFACE CONTOUR MAP
WITH TEST WELL LOCATIONS



Based on the results of this and on analysis of surface water from the marsh, the extent of potential pollution was predicted and locations for monitoring wells determined. Table 7-1 presents the wells that were constructed.

TABLE 7-1

WELL CONSTRUCTION DETAILS, WATER LEVELS AND WATER QUALITY (PHYSICAL)
(all wells equipped with 2-ft screen or well point)

Well	Well diameter (in.)	Well depth (ft)	Depth to water (ft)	Specific conductance (uMOHS/cm)	Temperature (°F)
1	2.5	60	46	210	65
2	1.5	60	44	220	65
3	2.5	50	33	210	65
4	1.5	45	36	270	65
5	2.5	40	27	240	67

1 in. = 2.54 cm
1 ft = 0.305 m
1°C = 5/9 (F-32)

Accountability and documentation should be emphasized in any monitoring program. Logs should be kept that indicate the date, time, method, and other pertinent conditions existing at the time of sampling. Wells should be kept locked and samples should be handled as indicated in "Procedures Manual for Monitoring Solid Waste Disposal Sites" [7]. In addition, where litigation is anticipated, it is valuable to use an independent lab for sample analysis.

7.2.5 Sample Collection

7.2.5.1 Materials and Equipment

The type of sampling device chosen for groundwater monitoring will depend upon the sludge landfill's physical setting and funding. Figure 7-3 is an example of a typical monitoring well. Important features include an impermeable backfill, PVC piping and well screen, and gravel fill around the well screen. Figure 7-4 illustrates the installion of well points to collect samples from several depths.

FIGURE 7-3

TYPICAL MONITORING WELL SCREENED OVER A SINGLE VERTICAL INTERVAL

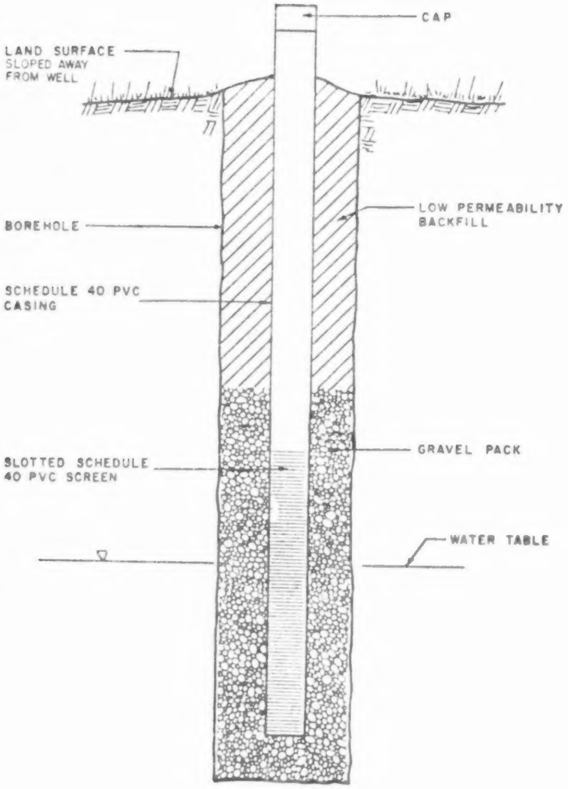
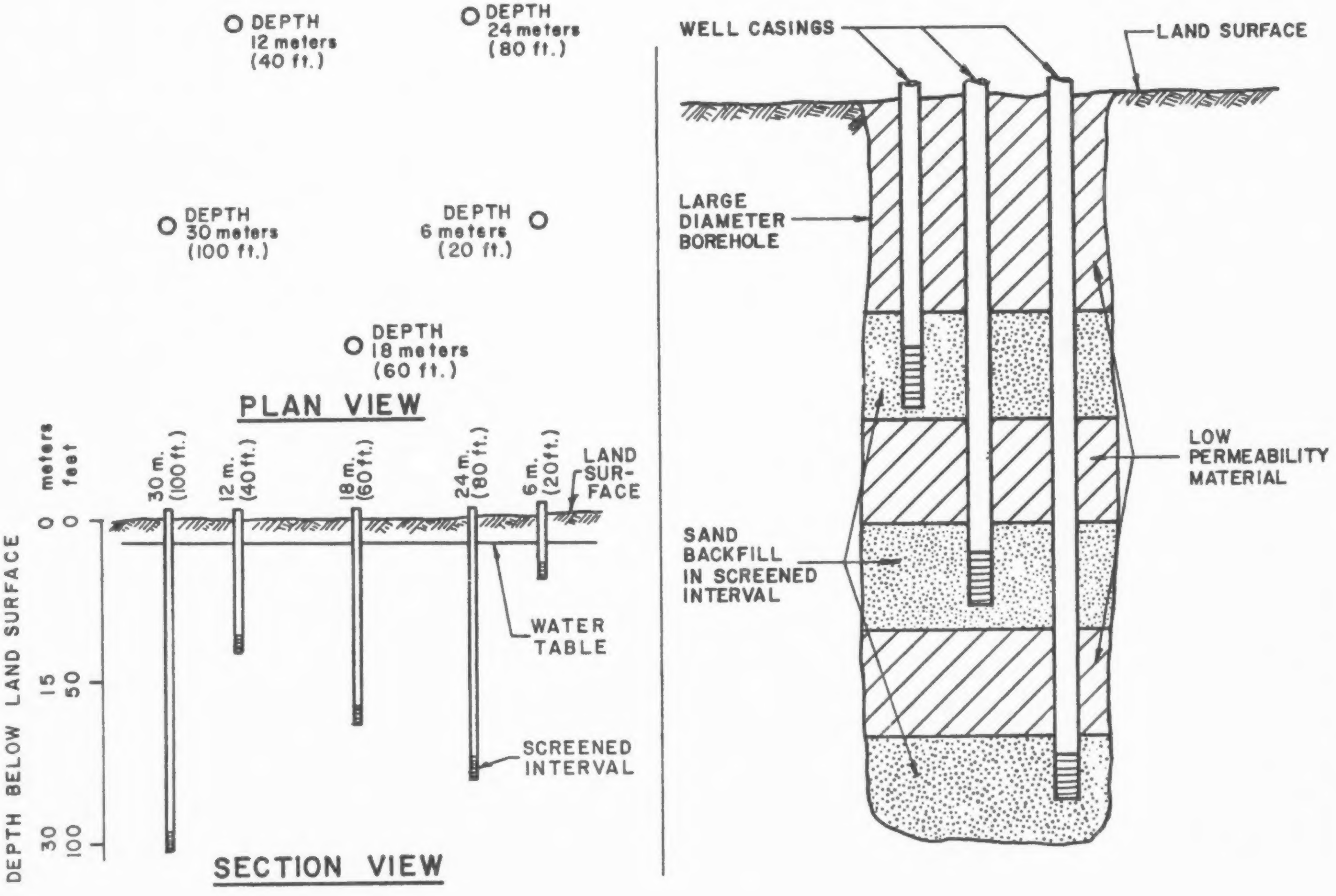


FIGURE 7-4

TYPICAL WELL CLUSTER CONFIGURATION [1]



The composition of the materials selected for groundwater monitoring should be examined for possible contamination and interference with the chemical analysis. For example, galvanized pipe should not be used when testing for trace metals. Inert materials such as ABS or PVC reduce the possibility of erroneous readings, although the glues used on the fittings can contaminate samplings. Disinfection of wells, equipment, and containers by chlorination or other means is required if bacteriological examination is included. Several excellent documents outlining containers and preservation techniques for individual species are available [1][10][11][12].

7.2.5.2 Collection Techniques

Well sample collection techniques deserve careful analyses. Whether the bail, air lift, or vacuum method is used, the interaction of these procedures with the prescribed analyses requires consideration [13][14]. The means of obtaining the sample depends upon the analyses to be performed. For example, sampling of groundwater for reduced species (e.g., H_2 and redox measurements) should exclude the possibility of air contamination or O_2 injection into the sample. Systems utilizing pumping or air injection would interfere with true in situ measurements. Collection techniques should remain consistent throughout the duration of the monitoring. Pumping a well for a certain period of time prior to obtaining a sample is recommended. At a minimum, the volume of the standing water should be removed. If time and the recovery of the aquifer permit, 2 to 3 volumes should be removed prior to sampling. Similarily, collection equipment (air lift versus bail) should remain the same. In this way, the results of the program will not be compromised due to collection variations.

7.2.5.3 Sampling Frequency

The frequency of sample collection is dependent upon the goals of a particular program (i.e., whether it is long or short term) and on the specific characteristics of the site (i.e., soils, climate). The estimated rate of travel of pollutants in a given hydrogeological setting will suggest intervals of time which will show a change in water quality. Analyses of the initial and second samplings may suggest an adjustment of the sampling frequency. Studies indicate that leachates frequently are released in slugs, or high concentrations, at periodic intervals that are seasonally or climatically influenced [6]. This may dictate intensified sampling efforts at certain times. Regulatory agencies often require quarterly sampling. Sampling frequency should reflect the requirements of the appropriate regulatory agencies as a minimum. However, the required sampling frequency is site specific and hence should be adjusted if experience indicates that more frequent samplings are necessary.

7.2.6 Analytical Parameters

The parameters or constituents included in the analysis of groundwater samples depend on such factors as monitoring goals and levels, funding, waste composition, uses of groundwater, regulatory requirements, etc. If the groundwater is potable, parameters for which drinking water standards have been established should be measured [15]. If high concentrations of certain heavy metals, or toxic chemicals, are detected in the sludge, they should be included on the groundwater monitoring list. No list of parameters applies to all cases. However, a recent study indicates that lead, iron and TOC are the constituents most frequently observed in leachate from sludge landfills and consequently may be considered as good indicator parameters. Based on sludge characteristics and a recent study [6], it is recommended that the following parameters be analyzed regardless of uses:

1. pH
2. Electrical conductivity or total dissolved solids (TDS)
3. Iron
4. Nitrate
5. Chlorides
6. Total organic carbon (TOC) (if not feasible, COD)
7. Heavy metals (expecially lead)
8. Methylene blue-active substances (optional, depending on sludge).

The water temperature and depth at the time of sampling should be noted. The results from the downstream and on-site wells should be compared with those from the background well and the drinking water standards or other pertinent regulations [15]. Seasonal variations in contaminant concentrations should be noted. Typical quantities of dissolved solids are presented in Table 7-2.

TABLE 7-2

RELATIVE ABUNDANCE OF DISSOLVED SOLIDS IN POTABLE WATER [16]

Major Constituents (1.0 to 1,000 mg/l)

Sodium
Calcium
Magnesium
Bicarbonate
Sulfate
Chloride
Silica

Secondary Constituents (0.01 to 10.0 mg/l)

Iron
Strontium
Potassium
Carbonate
Nitrate
Fluoride
Boron

Minor Constituents (0.001 to 0.1 mg/l)

Antimony
Aluminum
Arsenic
Barium
Bromide
Cadmium
Chromium
Cobalt
Copper
Germanium
Iodide
Lead
Lithium
Manganese
Molybdenum
Nickel
Phosphate
Rubidium
Selenium
Titanium
Uranium
Vanadium
Zinc

Trace Constituents (generally less than 0.001 mg/l)

Beryllium
Bismuth
Cesium
Gallium
Gold
Indium
Lanthanum
Silver
Thallium
Thorium
Tin
Tungsten
Zirconium
Platinum

7.2.7 Analytical Methods

7.2.7.1 Sample Size and Preservation

Table 7-3 is a brief description of sampling methods recommended by Chian and DeWalle for the sampling of concentrated leachate, as presented in "Procedures Manual for Groundwater Monitoring of Solid Waste Disposal Facilities" [1]. Information and methods of minimizing interferences are included in this table as well as recommendations concerning sampling containers and volumes required. This document also provides an excellent discussion of analytical methods for leachate analysis.

7.2.7.2 Field Testing Versus Testing in the Laboratory

The majority of tests performed on leachate samples are run in the analytical laboratory on samples which have been preserved by refrigeration or chemical means. A limited number of tests, however, can be performed at the sampling site on a freshly drawn sample. There are a number of advantages in field testing in which sample degradation is practically eliminated, along with the need for sample preservation, transportation, and handling. An added advantage is the ability to re-sample and re-analyze immediately, on site, if it is suspected that a particular sample is not representative or valid. There are also disadvantages encountered in field testing and these usually relate to the reliability of the particular method and equipment used for the test.

Some tests can be run in the field with the same methods and equipment which would be used in the laboratory and yield the same reliability. Among such tests are those involving the measurements of pH, oxidation, and specific ions by means of specific ion electrodes. The equipment used in these tests is available in portable models which are of equal applicability in the field and laboratory.

Other tests are sometimes performed exclusively in the field using methods and equipment specifically designed for field use. A number of commercial kits are available for such purposes. While offering distinct advantages, there are also disadvantages inherent in the use of field kits. An evaluation of field kit usage is presented in "Handbook for Monitoring Industrial Wastewater" [17].

7.3 Surface Water Monitoring

Surface water monitoring is usually implemented as a routine component of a total network. The proximity of a sludge landfill to surface water and drainage patterns will determine whether surface water monitoring is necessary.

TABLE 7-3

SAMPLE SIZE AND SAMPLE PRESERVATION[a]

Measurement	Vol. reg. (ml)	Container	Preservation	Holding time[f]	Standard Method Number[g]
Acidity	100	P,G[b]	Cool, 4°C	24 hrs	402
Alkalinity	100	P,G	Cool, 4°C	24 hrs	403
Arsenic	100	P,G	HNO_3 to pH < 2	6 mos	404
BOD	1,000	P,G	Cool, 4°C	6 hrs[c]	507
Bromide	100	P,G	Cool, 4°C	24 hrs	406
COD	50	P,G	H_2SO_4 to pH < 2	7 days	508
Chloride	50	P,G	None Req.	7 days	408
Chlorine Req.	50	P,G	Cool, 4°C	24 hrs	412
Color	50	P,G	Cool, 4°C	24 hrs	204
Cyanides	500	P,G	Cool, 4°C NaOH to pH 12	24 hrs	413
Dissolved Oxygen					402
Probe	300	G only	Det. on site	None	
Winkler	300	G only	Fix. on site	None	
Fluoride	300	P,G	Cool, 4°C	7 days	414
Hardness	100	P,G	Cool, 4°C	7 days	309
Iodine	100	P,G	Cool, 4°C	24 hrs	416
MBAS	250	P,G	Cool, 4°C	24 hrs	512
Metals					301
Dissolved	200	P,G	Filter on site HNO_3 to pH < 2	6 months	
Suspended			Filter on site	6 months	
Total	100		HNO_3 to pH < 2		
Mercury					315
Dissolved	100	P,G	Filter HNO_3 to pH < 2	38 days (glass) 13 days (hard plastic)	
Total	100	P,G	HNO_3 to pH < 2	38 days (glass) 13 days (hard plastic)	
Nitrogen					417
Ammonia	400	P,G	Cool, 4°C H_2SO_4 to pH < 2	24 hrs[d]	418
Kjeldahl	500	P,G	Cool, 4°C H_2SO_4 to pH < 2	24 hrs[d]	421
Nitrate	100	P,G	Cool, 4°C H_2SO_4 to pH < 2	24 hrs[d]	419
Nitrite	50	P,G	Cool, 4°C	24 hrs[d]	420
NTA	50	P,G	Cool, 4°C	24 hrs	--
Oil & Grease	1,000	G only	Cool, 4°C H_2SO_4 to pH < 2	24 hrs	502
Organic Carbon	25	P,G	Cool, 4°C H_2SO_4 to pH < 2	24 hrs	505
pH	25	P,G	Cool, 4°C Det. on site	6 hrs[c]	424
Phenolics	500	G only	Cool, 4°C H_3PO_4 to pH < 4 1.0 g $CuSO_4$/l-	24 hrs	574

TABLE 7-3
(continued)

Measurement	Vol. req. (ml)	Container	Preservation	Holding time[f]	Standard Method Number[g]
Phosphorus					
Ortho-phosphate, dissolved	50	P,G	Filter on site Cool, 4°C	24 hrs[d]	425
Hydrolyzable	50	P,G	Cool, 4°C H_2SO_4 to pH < 2	24 hrs[d]	
Total	50	P,G	Cool, 4°C	24 hrs[d]	
Total, dissolved	50	P,G	Filter on site Cool, 4°C	24 hrs[d]	
Residue					
Filterable	100	P,G	Cool, 4°C	7 days	208
Non-filterable	100	P,G	Cool, 4°C	7 days	
Total	100	P,G	Cool, 4°C	7 days	
Volatile	100	P,G	Cool, 4°C	7 days	
Settleable matter	1,000	P,G	None Req.	24 hrs	208
Selenium	50	P,G	HNO_3 to pH < 2	6 months	318
Silica	50	P only	Cool, 4°C	7 days	426
Specific conductance	100	P,G	Cool, 4°C	24 hrs[e]	205
Sulfate	50	P,G	Cool, 4°C	7 days	427
Sulfide	50	P,G	2 ml zinc acetate	24 hrs	428
Sulfite	50	P,G	Cool, 4°C	24 hrs	429
Temperature	1,000	P,G	Det. on site	None	212
Threshold odor	200	G only	Cool, 4°C	24 hrs	206
Turbidity	100	P,G	Cool, 4°C	7 days	214

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[a] More specific instructions for preservation and sampling are found with each procedure as detailed in the literature [1]. A general discussion on sampling water and industrial wastewater may be found in ASTM, Part 23, p. 72-91 (1973).

[b] Plastic or glass

[c] If samples cannot be returned to the laboratory in less than 6 hrs and holding time exceeds this limit, the final reported data should indicate the actual holding time.

[d] Mercuric chloride may be used as an alternate preservation at a concentration of 40 mg/l, especially if a longer holding time is required. However, the use of mercuris chloride is discouraged whenever possible.

[e] If the sample is stabilized by cooling, it should be warmed to 25°C for reading or temperature correction made and results reported at 25°C.

[f] It has been shown that samples properly preserved may be held for extended periods beyond the recommended holding time.

[g] The numbers in this column refer to the appropriate parts of the "standard Methods for the Examination of Water and Wastewater, 14th edition, APHA-AWWA-WPCF, 1975.

Selection of surface water sampling stations, equipment, and procedures should follow a methodical approach similar to that described for groundwater monitoring. Each surface water monitoring item should be evaluated in terms of compatability or possible contamination with the constituents to be analyzed.

Surface sampling stations should be located in areas which represent the greatest potential for contamination. These points can be determined after examining the pathways available for leachates to enter a surface water body. Consideration should also be given to selecting stations which can provide consistent samples throughout the monitoring program. Flow patterns and seasonal variations should be addressed when applicable.

Surface water sampling equipment should be suited to the goals of a particular program. Sampling equipment and procedures can range from continuous or intermediate automated samplers to manual collection by filling a container by hand. Manual sampling is almost always considered to be adequate.

Indicator parameters and analytical methods used for surface water samples should be consistent with selected procedures for groundwater sample testing. The effects of surface water mixing and interference with contaminants should be considered.

7.4. Gas Monitoring

More often than not, sludge landfills are located quite distant from structures and gas monitoring may not be required. When it is required, the gas of major concern is methane. Methane gas in concentrations in excess of 5% is explosive. If there are structures near the landfill (e.g., a wastewater treatment plant, residences, etc.) a methane gas control system should be installed and a monitoring program should be carried out.

The sampling devices should be located in whatever direction structures exist. Typically, sampling devices may be located near the property boundary and off-site on the landfill side of structures in pathways most susceptible to gas migration [18][19].

Gas sampling devices usually consist of simple, inexpensive gas probes. The probe is usually polyethylene, copper, or stainless steel tubing. Due to the small diameter of probes (<1/4 in. (0.6 cm)), a series of these devices can be situated at various depths within a single hole. Installation of gas probes is described in the literature [20][18].

The sample collection technique depends upon the type of sampling probe installed. Most methods require some form of evacuation, although the specific type may vary. The sampling frequency depends upon the particular monitoring program. The estimated rate of movement of gas in a particular soil may be useful for developing optimum periods. As a minimum, if gas monitoring is required, samples should be taken at the same time that water samples are taken. Most frequently a portable meter is used to monitor methane gas. This instrument indicates the percentage of methane gas up to the lower explosive limit of 5% methane.

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CHAPTER 8

COMPLETED SITE

8.1 Introduction

The purpose of this chapter is to provide guidance in developing a completed site plan. This plan should be first considered during the site selection process and finalized during the design process. Objectives of a completed site plan include:

1. Designate the operational procedures for site closure
2. Establish the criteria that must be addressed before planning the final site use
3. Determine the components of final site use that will ultimately lead to the selection of a site use that is publicly acceptable as well as technically practical

A plan for the final use of the landfill is a step toward acceptance of a proposed site. This is particularly true where there is active public participation in the site selection process. The local landfill should be shown to represent an immediate and future benefit to the community. On the other hand, projected site uses should be realistic both in concept and in the method portrayed.

Final site uses may have a longer life than the original filling operation. Because of the long-term nature of the final use, the completed site plan should be prepared at the same time that the landfill is being designed, since decisions regarding one can substantially affect the other. Each step of the landfill process--initial site preparation, installations of screening and buffers, placement of the final landfill cover, and revegetation--should be seen as steps toward achieving the final use [1].

By integrating the final site plans into the preliminary design, the ultimate value and cost of developing the final site can be enhanced. Leaving islands of undisturbed soil in strategic areas will enable the site to be developed and increase the overall value of the site. Setting aside part of the operating fees for final site development can provide the capital needed for site closure. If the land is to be sold, the question of liability and responsibility for regrading and monitoring should be considered. In New York, for instance, the landfill operator is responsible for monitoring and maintenance for 5 years after site closure regardless of whether he has sold the property or not [2]. However, in California the current property owner is usually held liable in court cases.

8.2 Procedures for Site Closure

The following operational procedures for closing a site are to be performed when either the entire sludge landfill or a segment of the landfill has been filled to capacity. These procedures can be conducted concurrent with on-going site operation. Procedures for proper site closure are outlined in Table 8-1.

TABLE 8-1

PROCEDURES FOR SITE CLOSURE

- No sludge should be left exposed. Trenches and lifts should be sufficiently covered. If trenches and lifts are unstable, they should be well marked using drums or wooden barricades.
- Although the rate of settling varies, maximum settlement will occur within the first year of landfilling. Accordingly, sufficient time should be allowed for the area to settle. As necessary, the area should be regraded to account for settlement.
- After maximum settlement has occurred, the area should be regraded to ensure proper drainage. Depressions and cracks should be filled using on-site or borrowed soil. Bulldozers and/or graders are normally used for spreading and grading the soil.
- One to 3 ft (0.3 to 0.9 m) of final cover may be applied. This cover may consist of top soil which was stripped and stockpiled prior to commencing the landfilling operation. Soil that is deficient in organics (e.g., sandy soil) may require a mixture of sludge at a ratio of 5:1 to 10:1.
- Check sediment and erosion controls and modify according to any change in grade.
- Construction of small structures (picnic tables shelters, etc.) may be undertaken in accordance with specifications in the final site use plan.
- Disassemble temporary structures and receiving areas not required for final site use.
- Hydroseed denuded areas with the appropriate mixture of grasses. Climate and final site use are a major factor in determining the type of grass and vegetation selected.
- Outline a timetable to ensure that the following features are inspected at regular intervals:
    1. Settlement, cover soil integrity, and need for grading
    2. Buffers and vegetation
    3. Sediment and erosion control facilities
    4. Fencing
    5. Leachate and gas controls
    6. Integrity of final site use facility
    7. Vandalism
    8. Monitoring

For several years after filling is completed the site should be inspected at monthly to quarterly intervals, as outlined in Table 8-1. Thereafter, inspection should be conducted at least annually. Additionally, sediment and erosion controls should be inspected during rainy periods to determine their effectiveness.

Upon completion of the site, a plan detailing the site development, operation, and controls should be prepared and recorded with the county records. The description should include general types and locations of wastes, depth of fill, and other information of interest to potential landowners [1].

8.3 Characteristics of Completed Site

When planning a final site use, critical factors that must be considered are settlement, bearing capacity, final grade, and control of leachate and gas, and vegetation [3].

8.3.1 Settlement

Settlement due to the volume reduction of sludge creates cracks or fissures in the cover material. It can contribute to substantial movement in the verticial and/or the horizontal direction, with displacements ranging from 6 in. (15 cm) to 3 ft (0.9 m). Settlement can occur within a few days of filling or can extend over many years. Experience has indicated that the site may have to be regraded up to 3, 4, or 5 years after closure. Research has been conducted in the laboratory on the settlement of landfilled paper mill sludges [4][5], but additional work is needed in order to predict the settlement of landfilled municipal sludges.

The rate and extent of settlement are controlled by the interaction of a number of variables, including:

1. Sludge characteristics
2. Landfilling method
3. Soil characteristics

Of these, the characteristics of the sludge have the greatest impact.

8.3.1.1 Sludge Characteristics

Relevant sludge charcteristics include:

1. Solids content
2. Volatile solids content
3. Particle size and configuration

A detailed discussion of treatment processes and resulting sludge types has been included previously. Sludge with a low solids content (15-20% solids) can be expected to settle more than sludge with a higher solids content ($\geq$28% solids). Sludge may dewater through evaporation, infiltration (into porous soils) or separation; but in any case, as it loses moisture, the pore spaces increase. The result is a loss of volume and consequent settling.

Other factors that influence the stability of the completed site are the volatile solids content and the size and configuration of sludge particles. In general, the higher the volatile solids content, the greater the degree of settlement. Sludges with large, poorly sorted particles will also settle to a greater extent.

8.3.1.2 Landfilling Method

The landfilling method influences the potential for settlement. Landfilling methods that call for the mixture of sludge with soil or refuse settle in a different fashion than a method using only sludge.

Sludge with a lower solids content disposed in trenches may stratify into liquid and solid phases. The solids may settle to the bottom of the trench, resulting in a liquid layer forming at the top. If this separation occurs, rapid settlement of the solid fraction results. Conversely, stratification may occur where solids rise to the surface. This buoyant effect is caused by gases of decomposition which adhere to sludge solids.

Area fill landfills (where the sludge is not contained) may experience horizontal movement or creeping. Area fill methods are also more susceptible to variable climatic conditions, which also affect landfill stability.

8.3.1.3 Soil Characteristics

The amount of interim and final cover affects the degree of settlement. Often termed surcharge, the cover enhances percolation of liquid into the surrounding soil by applying pressure on the sludge. The ability of the cover material to bear weight, inhibit water infiltration, and hold vegetation is important when predicting sludge settlement. Soil used for sludge bulking also affects the settling potential.

8.3.2 Bearing Capacity

The bearing capacity of a completed landfill is the measure of its ability to support foundations. The bearing capacity of the sludge landfill is dependent on the following:

1. Sludge characteristics
2. Landfilling method
3. Soil characteristics (bulking and cover)
4. Vegetation

Currently, limited information is available on the bearing capacity of sludge landfills. Although laboratory scale sludge bearing tests have been conducted on industrial wastewater sludges and solid waste, it is questionable whether these tests are valid on a large-scale municipal wastewater sludge landfill over long periods of time. Although natural soils produce bearing test values that fall within a predictable range and are reproducible, it is not known whether tests on sludge will produce similar results. Therefore, it is suggested that construction of structures on a sludge landfill site be restricted to areas of undisturbed soils where landfilling of sludge has not occurred.

8.3.3 Final Grade

The final slopes in the landfill should generally range from 2 to 5%. Factors that influence the final grade are:

1. Climate
2. Vegetation
3. Soil characteristics

In relatively dry climates with suitable vegetative cover, slopes may safely exceed 5%. On the other hand, in areas with high rainfalls it may be necessary to use extensive erosion and drainage control for slopes above 5%.

8.3.4 Leachate and Gas

Leachate and gas from sludge landfills will continue to be produced long after the fill is completed. If not properly controlled, gas can accumulate in enclosed areas or structures. Also, at certain concentrations gas can stunt or kill vegetation. Leachate can cause serious pollution of groundwater and surface water if not properly controlled.

An impermeable cap placed over a sludge landfill after completion will decrease the potential for leachate by decreasing the amount of surface water infiltration. Gas and leachate controls must be incorporated into the design (see Chapter 5, Design).

8.3.5 Vegetation

In most instances, a completed site will require some vegetation. Through careful selection, plants can enhance the attenuative properties of the soil as well as perform the traditional functions of erosion control, infiltration management (see Figure 8-1), and visual enhancement.

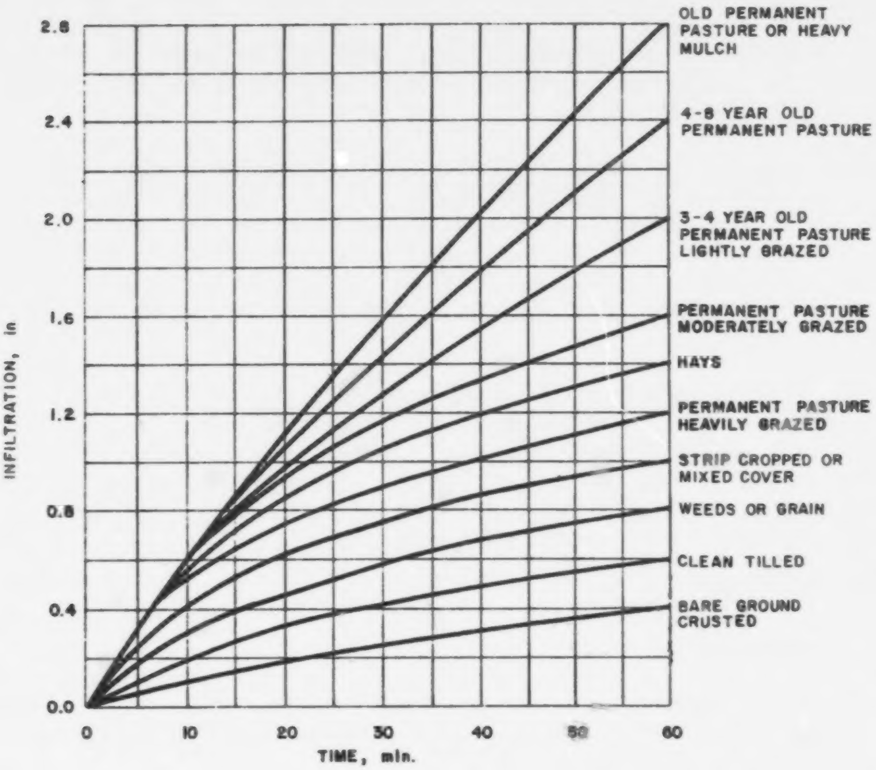
Winter rye has been found to be effective in enhancing the fertility of the soil. It has the advantage of quick growth and hence can provide effective early erosion control. If planted with bermuda grass it can serve to stabilize slopes and reduce runoff. Bunch grasses, such as canary grass, and sod grasses generally provide good cover and grow well in conditions found in landfills. Where stabilized sludge has been landfilled, trees can be planted and will generally do well. Information concerning suitable cover crops is available from the U.S. Department of Agriculture, Soil Conservation Service. In addition, local agencies such as county extension services and local universities are valuable sources of data.

8.4 Completed Site Use

The selection and design of final land uses should be the result of a comprehensive land planning study that considers all aspects of proposed filling operations as well as final uses. The objectives of the land planning study should be to identify uses that will:

FIGURE 8-1

INFILTRATION RATES FOR VARIOUS CROPS



1. Take advantage of the opportunity for permanent improvements to the landfill that are available after filling is completed
2. Eliminate or minimize potential off-site conflicts with existing or future development through the careful siting of the fill, maintenance of an open space separation, and utilization of natural screening and buffers
3. Be compatible with and complementary to existing natural conditions and activities and help meet the future needs of the community

The land planning process should be integrated with site selection and be carefully organized to seek out relevant information relating to the site. Four important steps to follow are:

1. Perform site inventory. The existing land use must be identified and the impact of curtailment of current land use (whether it be recreation, open space, etc.) must be determined. The inventory might include topography, vegetation, water bodies, public facilities, etc. Information can be obtained from aerial photos, site visits, and review of public records.

2. Evaluate of Needs. To assess future needs, an evaluation of local plans for population, utility, and highway projections should be attempted. Local planning offices should be contacted to determine current land use policies for the area of consideration.

3. Identify alternatives and select completed site use. Using the information obtained above, an evaluation should be conducted noting advantages and disadvantages of each potential use. If site characteristics and constraints are known, alternative ultimate land uses can be evaluated in terms of technical feasibility and costs. The optimum site use can then be selected.

4. Select, design, and implement completed site use. After selecting completed site use, a master plan should be prepared. It should designate the scheme for cover soil stockpiling, maintaining positive drainage by regrading, revegetation, sediment control, leachate control, ground or surface water monitoring, and maintaining acceptable environmental and aesthetic conditions.

8.5 References

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CHAPTER 9

MANAGEMENT AND COSTS

9.1 Introduction

The operation of a sludge landfill is dependent upon a number of factors including the volume and type of sludge received and site conditions. It is the intent of good landfill administration to efficiently manage these factors in a way which adequately protect the environment. However, due to more stringent regulations and spiraling construction costs, the operation of a sludge landfill is becoming increasingly costly.

Management of a sludge landfill involves a wide range of responsibilities and requires a number of specialties. The landfill manager has operational responsibilities (conformance to the design and regulations, day-to-day operation, security, and equipment maintenance and replacement); social responsibilities (public relations and personnel hiring, training, and safety); and fiscal responsiblities (equipment and personnel recordkeeping, operational recordkeeping, budgets, and financing). Managers of sludge landfills should become involved in the project early in its planning stage. Continuity of management is desirable throughout the operating life of the landfill.

9.2 Management Responsibility

Operation of sludge landfills may be under public or private management. A description of typical alternative managing organizations is detailed below.

9.2.1 Municipal Operations

Most sludge landfills are municipal operations. Authority for operating and managing such landfills is usually entrusted either to the sewer department or to the department of public works. Sewer departments often manage sludge landfills since wastes received at that sites are generated by treatment plants owned by sewer departments. Disposal of residuals is part of the wastewater treatment process at large, and costs incurred are usually financed through sewer fees. Also, vehicles used to haul sludge are often owned and operated by the sewer department. Finally, many sludge landfills are located at or near the treatment plant, and the property is owned by the sewer department.

However, management of sludge landfills is increasingly being assumed by public works departments. This may be more appropriate, particularly when landfills are not located on the treatment plant property since operation of a sludge landfill is a construction activity that is well-suited to the experience and resources of public works departments.

9.2.2 County Operations

Management of sludge landfills by county governments is less prevalent than that of municipal governments. As with municipal operations, county landfills are often managed either by the sewer department or by the public works department. However, County landfills usually serve larger populations and geographic regions than municipal landfills and the attendant economies of scale and the greater land areas available may make such operations more desirable than municipally-managed sludge landfills. The choice of county or municipal management usually is determined by whether the sewer department is administered by the municipality or the county. Nevertheless, due to the potential advantages of county-wide sludge landfills management, this should be considered even when sewage is treated by several municipalities.

9.2.3 Sanitary District Operations

Sanitary districts are more likely to be responsible for managing sludge landfills than are their municipal counterparts (sewer departments) since no alternative authority is available. Financing for sludge landfills managed by sanitary districts is often easier to secure since they may have provisions for levying special taxes. Also, these districts generally service greater populations and may serve several jurisdictions. As a result, sanitary districts are generally better financed and equipped to operate sludge landfills due to the economies of scale.

9.2.4 Private Operations

Next to municipal operations, privately-managed operations are the most prevalent type of sludge landfill. Sludge landfills may be operated under contract, franchise, or permit arrangement. In contract operations, the presiding government agency contracts with the private operator to dispose of sludge for a fixed lump sum fee or for a unit charge per ton, cubic yard, or truck load. If a unit charge is the basis of the contractual arrangement, the government agency usually guarantees a specified minimum dollar amount to the contractor. Franchises usually grant the operator permission to dispose of sludge from specified areas and charge regulated fees. Permits allow the operator to accept sludge for disposal without regard to source.

Private operations may benefit government agencies that have limited capital available for construction and initial operation of a sludge landfill. Also, private operators may be able to operate at a lower cost. However, precautions should be taken to ensure that private operators will provide adequate environmental safeguards. For this reason, contract arrangements are usually the best choice since operating and performance standards can be written into the contract.

9.3 Equipment Management and Documentation

Equipment cost is the largest single expense incurred in the operation of most sludge landfills, exceeding even the labor cost. Accordingly, the proper selection, purchase, operation, and maintenance of equipment will contribute substantially to the cost efficiency of a landfill. Following are some important facets to consider in managing equipment at sludge landfills.

9.3.1 Selection and Purchase

A determination of the type and number of machines needed to operate a sludge landfill is a function of production (speed at which the equipment can accomplish an assigned task when operated appropriately), size of the site, quantity of sludge handled, landfilling method, types of soil, and availability of parts and service. Guidance was provided in Chapter 6 (Operation) on the selection of equipment under various conditions. It should be remembered, however, that a determination of equipment needs for an actual sludge landfill should be made on a case-by-case basis.

Having chosen appropriate equipment, the following cost categories should be considered prior to purchasing:

1. Owning cost. This consists of the price of the equipment, the interest charges, the taxes, and the insurance premium.
2. Operating cost. This includes costs for maintenance and fuel. Maintenance costs must include not only repairs, but also the price of oil, grease, and labor for preventive maintenance.
3. Downtime cost. Every effort must be made to keep this cost to a minimum. Standby equipment cost must also be considered here. Since the operation must continue when a machine is down, back-up equipment will be needed. Equipment rentals may be appropriate.

4. Resale value. This includes the depreciation rate on the machine and what its potential market value may be when the equipment is no longer needed.

Consideration of all of the above cost factors will enable managers of sludge landfills to get a complete picture of the actual total equipment cost. In addition to the purchase cost, operating and downtime costs must be included in any cost analysis. These can amount to a substantial percentage of the owning cost over the life of the sludge landfill. Of course, the landfill manager can recoup some costs through resale of the equipment.

9.3.2 Operation

The nucleus of the sludge landfill operation is the equipment. To maximize efficiency, prevent equipment damage and personal injury, and ensure an environmentally sound and economical operation, equipment should only be operated by competent and qualified personnel. Accordingly, operators should have extensive experience in equipment operation. If new equipment operators are trained at sludge landfills, a qualified operator should ride along until the employee is thoroughly competent on the machine and the new operator should be checked and tested by the supervisor before a machine assignment is made. Operators should work cautiously at sludge landfills, since the unstable nature of sludge can cause equipment operated by even the most experienced personnel to become mired in sludge. After some experience, however, operators can learn to use their equipment more efficiently in the landfill environment.

9.3.3 Maintenance

Often equipment maintenance is more expensive than the amortized annual cost of equipment purchase. Thus, equipment maintenance is a high-cost item and constitutes a substantial part of the on-going operational expense of sludge landfills.

Initially, a sludge landfill manager should outline a comprehensive preventive maintenance program. If preventive maintenance is performed daily, the manager has taken a major step toward lowering maintenance costs. Normally, the equipment operator performs routine maintenance each day on his machine; e.g., checking water and oil, lubrication, keeping tracks clean, blowing out radiators with an air compressor, etc. It is critical that these maintenance tasks be performed daily, and the supervisor should be personally responsible for ensuring that these tasks are performed. In some larger landfill operations, a full-time or part-time mechanic is assigned to perform maintenance and repairs of all of the landfill equipment.

Sludge landfill managers should make sure that the operation manual for each piece of equipment is readily available. Machine operators should consult the manuals in order to be familiar with the daily service needs of their equipment. These manuals should also be available to mechanics to ascertain the specific service requirements for each piece of equipment.

Equipment with a maintenance warranty will provide guidelines for maintenance that should be strictly followed to preserve the warranty for the designated period. Failure to adhere to these guidelines could increase maintenance costs.

9.3.4 Recordkeeping

A daily report should be completed by the operator for the equipment that he has operated that day. Sludge landfill managers should ensure that these records are complete, up to date, and accessible. The objective is both to ensure more complete maintenance and to lower maintenance costs. A sample form to be completed for this task has been included as Figure 9-1.

9.4 Personnel Management and Recordkeeping

Next to equipment, personnel is usually the largest single expense in a sludge landfill operation. Careful screening and hiring of employees and subsequent training of personnel develops an efficient operation. A safety program should be instituted as part of initial personnel training and conducted thereafter on an on-going basis. A detailed description of personnel management practices is included below.

9.4.1 Personnel Requirements and Hiring Practices

A description of personnel positions at sludge landfills and an overview of personnel requirements was described earlier in Chapter 6 (Operation). The most prevalent position at sludge landfills is that of equipment operator. For most sites, the number of personnel will be equal to or less than the number of machines. Often one person can be used to

FIGURE 9-1

EQUIPMENT INSPECTION FORM [1]

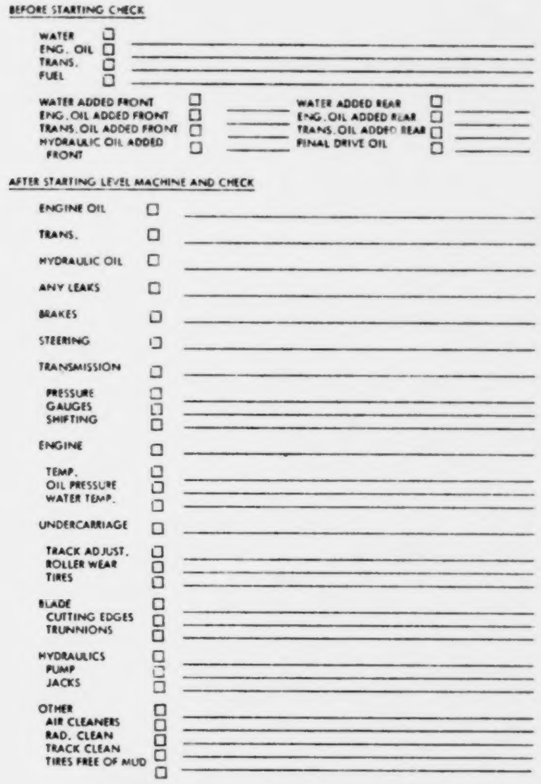
Site: ____________

Machine: ____________

Date: ____________

Completed By: ____________

Hour Meter Reading: ________



BEFORE STARTING CHECK

WATER ☐ ____________
ENG. OIL ☐ ____________
TRANS. ☐ ____________
FUEL ☐ ____________

WATER ADDED FRONT	☐	______	WATER ADDED REAR	☐	______
ENG. OIL ADDED FRONT	☐	______	ENG. OIL ADDED REAR	☐	______
TRANS. OIL ADDED FRONT	☐	______	TRANS. OIL ADDED REAR	☐	______
HYDRAULIC OIL ADDED FRONT	☐	______	FINAL DRIVE OIL	☐	______

AFTER STARTING LEVEL MACHINE AND CHECK

ENGINE OIL ☐ ____________
TRANS. ☐ ____________
HYDRAULIC OIL ☐ ____________
ANY LEAKS ☐ ____________
BRAKES ☐ ____________
STEERING ☐ ____________
TRANSMISSION ☐ ____________
  PRESSURE ☐ ____________
  GAUGES ☐ ____________
  SHIFTING ☐ ____________
ENGINE ☐ ____________
  TEMP. ☐ ____________
  OIL PRESSURE ☐ ____________
  WATER TEMP. ☐ ____________
UNDERCARRIAGE ☐ ____________
  TRACK ADJUST. ☐ ____________
  ROLLER WEAR ☐ ____________
  TIRES ☐ ____________
BLADE ☐ ____________
  CUTTING EDGES ☐ ____________
  TRUNNIONS ☐ ____________
HYDRAULICS ☐ ____________
  PUMP ☐ ____________
  JACKS ☐ ____________
OTHER ☐ ____________
  AIR CLEANERS ☐ ____________
  RAD. CLEAN ☐ ____________
  TRACK CLEAN ☐ ____________
  TIRES FREE OF MUD ☐ ____________

operate two or more machines (since 100% utilization of all equipment is often not required). For the larger sites, especially codisposal sites, the number of personnel may exceed the number of equipment pieces. These surplus personnel may be on-site superintendents, equipment mechanics, laborers, or check station attendants.

Hiring should be done in compliance with equal employment opportunity and nondiscrimination-in-hiring practices. When considering an applicant for a position, these procedures should be followed:

1. The applicant should complete an employment application form.
2. Supervisors should personally interview each applicant. The applicant should be questioned closely on past work experience to determine qualifications. The importance of the job should be explained fully with emphasis on the need to maintain a sanitary condition and to prevent environmental degradation.
3. The applicant's past employers and character references should be checked and the applicant's reliability and work record determined. The applicant's statements concerning experience and qualifications should be verified. Tests to determine the applicant's ability to perform the work are highly desirable.
4. If a decision is made to hire, arrangements should be made for the applicant to be given a thorough physical examination.

These hiring practices will help achieve a high standard for new employees.

9.4.2 Training

New employees should not only learn the tasks required for their positions, but also understand the purposes and importance of the sludge landfilling operation. Except for the largest operations, comprehensive training programs are not likely to be designed or conducted by landfill management. Training Programs have been prepared for refuse landfills by the U.S. Environmental Protection Agency, the American Public Works Association, and various educational institutions [1][2][3]. Since many of the procedures employed at refuse landfills are similar or identical to those employed at sludge landfills, these programs can be useful. Programs may take the form of classes conducted by these agencies or the provision of guideline information for training activities conducted for the employees. Equipment manufacturers are another valuable source of information on training procedures.

9.4.3 Safety

Managers of sludge landfill operations have an obligation to maintain safe and secure working conditions for all landfill personnel and also to see to it that safety rules are written, published, and given to each employee.

The landfill manager should establish a safety training program and should express, by example, a commitment to that program. Ideally, one man should be assigned the task of conducting the program and in assessing the compliance and efficacy of the program. A supervisor or foreman, because of his proximity to the operation is the logical choice for this position.

A safety checklist prepared by the National Solid Waste Management Association has been included as Figure 9-2. Although this checklist was prepared for municipal refuse landfills, most of the items are relevant to sludge landfill operations.

Privately operated landfills are required by Federal law to maintain up-to-date Occupational Safety and Health Act (OSHA) form records and to post the current OSHA employment poster. When an inspection is made of the landfill, the inspector will request to see all of the OSHA record-keeping forms. If they are not up to date, it can result in a citation and fines. Any records on safety meetings and preventive maintenance, as well as posters and brochures, will be considered by an inspector as an act of good faith and will indicate that an effort is being made to comply.

9.5 General Management and Recordkeeping

In addition to direction of equipment and personnel, a manager has numerous other responsibilities which must be performed to ensure a safe and efficient operation. These include the completion of activity records, the evaluation of operational performance, on-site supervision, public relations, and security. More details on these tasks are outlined below.

9.5.1 Activity Records

Complete records of the activity at sludge landfills may be needed either (1) to compile waste receipt records for billing purposes; (2) to assess the rate of cover utilization for future stockpiling needs; and/or (3) to gauge the overall efficiency of the landfill. Figure 9-3 is a sample form which could be used to record the quantity of sludge received from each incoming truck on a single day. If this information is available from the wastewater treatment plant, that data may be used. The daily sludge quantity can be totaled at the bottom of the daily form and

FIGURE 9-2

LANDFILL SAFETY CHECKLIST [2]

BUILDING EXITS (OSHA 1910.35 - 1910.37)

1. Doors swing with exit travel
2. Marked with lighted signs
3. Not locked so that they may be used from the inside at all times
4. Keep free of obstructions
5. Non-exit doors which can be mistaken as an exit as an exit are marked "No Exit"
6. Single exits are allowed for rooms containing less than 25 people

Combustible, Oxidizing, and Flammable Agents, When Using (OSHA 1910.101-1910.116)

7. Electrical installation and static electricity are controlled or maintained
8. Heating appliances are controlled or maintained in a safe manner
9. "Hot" work (welding) controlled or maintained in a safe manner
10. At least one 20 pound Class B fire extinguisher is within 25 feet of a storage area
11. ICC approved metal drums are used for storage from 5-60 gallons
12. Not more than required for one day or shift stored outside storage cabinet

COMPRESSED AND LIQUIFIED GASES (OSHA 1910.101-1910.116)

13. Charged and empty cylinders are separated
14. Cylinders are grouped by type and stored in vertical positions
15. Cylinders are not stored near other combustible material
16. Cylinders are supported so that they cannot be tipped over
17. Cylinder caps are in place on all cylinders which are not in use
18. Oxygen cylinders are not stored within 20 feet of other types of gases

DRAINAGE

19. Drains are vented to prevent collection of combustible gases
20. Grease and oil prevented from entering public sewage systems

ELECTRICAL EQUIPMENT (OSHA 1910.308-1910.309)

21. All outlet and junction boxes are properly covered
22. All portable electrical tools and appliances are properly grounded
23. Records maintained for inspection or portable electrical tools and appliances
24. Electrical cabinet doors with exposed conductors of 50 volts or more are securely fastened
25. Enclosures around high voltage electrical equipment are marked
26. Frayed cords, cables, and loose wires regularly removed from service
27. Switch boxes are identified as to equipment they control

EMERGENCY LIGHTING

28. Exits and necessary ways to exits are illuminated
29. Exit signs are illuminated to at least 5 foot candles

FIRE EXTINGUISHER EQUIPMENT (OSHA 1910.157)

30. Extinguishers are inspected monthly for physical damage
31. Inspection records are kept indicating inspector
32. Maintenance performed yearly, hydrotested every 5 years, if required
33. Inspection tags marked by month and year
34. Extinguishers conspicuously installed and properly marked for use by type of fire (A,B,CorD)
35. The top of portable extinguishers (less than 40 lbs) mounted no more than 5' above the floor
36. The top of portable extinguishers (40 lbs or more) mounted no more than 3-1/2' above the floor

FIRST AID (OSHA 1910.151)

37. An approved first aid kit is available
38. Emergency numbers of company-approved doctors and hospitals posted in appropriate locations
39. Trained personnel available

HAND AND PORTABLE TOOLS (OSHA 1910.241-1910.247)

40. All useable tools have guards properly installed
41. All portable electrical tools are tested monthly for ground
42. Records kept of inspection (item 41)
43. All tools in safe operating condition are free from worn or defective parts
44. Jacks and hoists are legibly marked with the load rating

HOUSEKEEPING

45. Material on walls/shelves stored in a safe and orderly manner
46. Facility is in a clean, orderly, and sanitary condition
47. Hoses, welding leads, drop lights, etc. are rolled and properly stored
48. Permanent aisles and passageways are free of obstructions
49. Permanent aisles and passageways are permanently marked

ILLUMINATION

50. Sufficient quantity (20 foot candles or greater)
51. Uniform distribution
52. Well directed

INDUSTRIAL SANITATION (OSHA 1910.141)

53. Clean, available drinking fountains
54. Facilities are maintained in a clean and stocked condition
55. Hot water available
56. Individual towels and drinking cups available
57. Toilet facilities are within 200 feet of working area for each sex

INDUSTRIAL TRUCK: FORKLIFT (OSHA 1910.178)

58. Brakes in good operating condition
59. Guard behind fork is in place (to guard from load falling to the rear)
60. Load capacity of truck marked
61. No one except operator permitted to ride
62. No one stands or walks under raised forks
63. Overhead guard to protect against falling objects
64. Recharging/refueling done in a "No Smoking" isolated area
65. Training program for operators
66. Warning devices (horn) working

LADDERS (OSHA 1910.25-1910.28)

67. Anti-slip safety steps used on portable ladders
68. Caution exercised when metal ladders used in electric current areas
69. Caution exercised when metal ladders used with portable electric tools
70. Ladders inspected monthly with inspection records kept
71. Straight ladders properly secured

FIGURE 9-2 (Continued)

LIQUID PETROLEUM GASES (OSHA 1910.110)

☐ 72. Bulk storage (126 to 500 gallons) at least 10 feet from building
☐ 73. Bulk storage (501 to 2,000 gallons) at least 25 feet from building
☐ 74. Bulk storage (251 to 2,000 gallons) at least three feet separation between tanks
☐ 75. Containers labeled by size (in pounds or gallons)
☐ 76. Containers labeled with pressure in "gauge psi"
☐ 77. Containers labeled by type of L.P.G.
☐ 78. Containers have safety relief and shut-off valves
☐ 79. Containers stored away from exits
☐ 80. Distance between L.P.G. containers and flammable liquid containers is 20 feet
☐ 81. No containers are stacked one above the other
☐ 82. Containers are stored in a "No Smoking" area

MACHINE GUARDING (OSHA 1910.211-1910.222)

☐ 83. Abrasive wheels in accordance with type of work
☐ 84. Abrasive wheels in good condition
☐ 85. Abrasive wheels labeled and in accordance with rpm ratings
☐ 86. Abrasive wheels uniform in diameters
☐ 87. Air nozzles used for cleaning meet 30 psi limit
☐ 88. All rotating, cutting shearing, screw and worm, blending, and forming motions guarded
☐ 89. Safety precautions understood and used by shop employees
☐ 90. Steady rests on grinders meet 1/8" adjustment to wheel requirement

PERSONAL PROTECTIVE EQUIPMENT (OSHA 1910.95, 1910.132-1910.140)

☐ 91. All protective equipment maintained in safe working condition
☐ 92. Ear protection worn when noise dBA greater than 90 for 8 hours
☐ 93. Ear protection worn when noise dBA greater than 95 for 4 hours
☐ 94. Ear protection worn when noise dBA greater than 100 for 2 hours
☐ 95. Ear protection worn when noise dBA greater than 105 for 1 hour
☐ 96. Ear protection worn when noise dBA greater than 110 for 1/2 hour
☐ 97. Ear protection worn when noise dBA greater than 115 for 1/4 hour
☐ 98. Eye and face protection provided where reasonable probability of injury exists
☐ 99. Respiratory protective equipment worn when air is contaminated (dust, gases, etc.)
☐ 100. Safety shoes, caps, gloves worn when necessary

STAIRS (OSHA 1910.21-1910.24)

☐ 101. Angle of rise is between 30 to 50 degrees
☐ 102. Fixed stairs have at least a 22" width
☐ 103. Fixed stairs have at least a 1000 lbs. load strength
☐ 104. Non-slip treads are present
☐ 105. Stair railings are 30-34" from top rail surface to forward edge of step
☐ 106. Stairways less than 44" wide (both sides enclosed) have at least one handrail
☐ 107. Stairways less than 44" wide (one side open) have at least one stair railing on open side
☐ 108. Stairways over 44" wide (both sides open) have two railings
☐ 109. Standard railings are 42" nominally from top surface of floor
☐ 110. Wood railing posts at least 2" x 4" stock spaced not to exceed 6 feet
☐ 111. Pipe railings and posts at least 1-1/2" nominal diameter
☐ 112. Pipe railing posts spaced not to exceed 8 feet
☐ 113. Structural steel railings and posts at least 2" x 2"
☐ 114. Structural steel railing posts spaced not to exceed 8 feet

VENTILATION (OSHA 1910.94)

☐ 115. Exhaust system for removal of toxic fumes and dust from work area

WALKING, WORKING SURFACES (OSHA 1910.21-1910.32)

☐ 116. Aisles and passageways unobstructed
☐ 117. Permanent walkways marked
☐ 118. Floor hole openings guarded and marked
☐ 119. Floor surfaces in good condition and uncluttered

WELDING, CUTTING, HEATING OR BRAZING (OSHA 1910.251-1910.254)

☐ 120. Acetylene not used at pressures greater than 15 psig
☐ 121. Eye protection worn, where required by extent of hazard
☐ 122. During welding operations, appreciable combustibles more than 35 feet away
☐ 123. During welding operations, floor swept clean of combustibles within 35 feet
☐ 124. Fire watch practiced, where necessary
☐ 125. Frame of electric welding machine grounded

HEAVY EQUIPMENT SAFETY REQUIREMENTS

☐ 126. Each piece of equipment has roll-over protection (see Section X-"Roll Over Protection Schedule")
☐ 127. Each piece of equipment has fire extinguisher (20 lbs. ABC Minimum)
☐ 128. All heavy equipment is equipped with backup alarm
☐ 129. All machines operating at night equipped with headlights
☐ 130. Seat belts are on all equipment with roll-over protection

MEDICAL AND FIRST AID

☐ 131. Medical personnel available for advice and consultation
☐ 132. Suitable place to render first aid

ROADS

☐ 133. Adjacent road (City, State, etc.) is clear of debris and mud
☐ 134. Where possible, warning sign or light, "TRUCK ENTRANCE"
☐ 135. Landfill road crowned and proper drainage
☐ 136. Landfill road kept properly cleaned of debris
☐ 137. Landfill road has proper dust control by means of a water wagon or water truck
☐ 138. Traffic Control Signs (Landfill) - Stop sign (for vehicle leaving landfill before entering public street)
☐ 139. Traffic Control Signs (Landfill) - Speed limit signs
☐ 140. Traffic Control Signs (Landfill) - No parking signs

LANDFILL SITE

☐ 141. All underground cables, pipes, etc., are clearly marked and identified
☐ 142. Utility wires are of sufficient height to allow clearance for all equipment using landfill
☐ 143. Security fences and landfill site is kept free as possible of blowing paper and debris

FIGURE 9-3

DAILY WASTE RECEIPT FORM

Truck Ident.	Time*	Sludge		Sludge Weight or Volume
		Source†	Type‡	
Totals				

Instructions: To be completed for each truck, each time it makes a delivery.

* Only record time at 15-minute intervals
† Sources: Code for Contributing Treatment Plant
‡ Types: G = grit; DI = digested; CT = chemically treated

transferred to the monthly summary included as Figure 9-4. The monthly summary can be used to record the sludge quantity received, as well as cover soil utilization, personnel and machine hours, and miscellaneous expenses.

9.5.2 Performance Evaluation

Generally, a state or local regulatory agency determines if the landfill operation is being conducted in a manner that adequately protects the environment. The concern of the landfill management, whether publicly or privately operated, helps guarantee an effective operation. The management of the organization operating the landfill should periodically evaluate the operation. The operating and supervisory personnel should be aware that these evaluations will be made, but the specific dates should not be made known in advance.

FIGURE 9-4

MONTHLY ACTIVITY FORM

Site: ____________________

Month: ____________________

Completed By: ______________

Day	Sludge		Cover material				Man hrs.	Machine hrs.		Expense		Site hrs.
	Loads	Tons	Begin	Rec'd	Used	Remain		Use	Down	$	Type	
1												
2												
3												
4												
5												
6												
7												
8												
9												
10												
11												
12												
13												
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21												
22												
23												
24												
25												
26												
27												
28												
29												
30												
31												
Totals												

1 ton = 0.907 Mg

9.5.3 On-Site Supervision

For safety reasons, it is desirable to have two or more persons working at sludge landfills. This can easily be accomplished at large landfills where more than one person is needed for daily operation. On small sites requiring only one operator, a second person should visit the site daily or the single operator should phone or check in at the end of each day. At a large site a foreman may be required with appropriate echelons of subordinate supervisors. A multishift operation would require supervisors for each of the shifts as well as an overall manager. No matter what the size of the operation, one person should be responsible for safety during operating hours and be familiar with OSHA regulations and procedures.

9.5.4 Public Relations

As noted in Chapter 4 (Public Participation Program), sludge landfills can be an emotional issue among the citizenry, especially those persons living in the vicinity of the site. Good housekeeping practices, such as control of odors (via prompt application of cover to sludge and spot application of lime to sludge spills) as well as other efforts to protect the environment, are important in gaining public acceptance.

Other public relation techniques that may be employed are periodic news releases concerning the progress of the fill, citizen participation in the completed site design, encouraging public visits to the site, and establishing a mechanism for handling complaints from the public.

9.6 Cost Recordkeeping

A primary duty of sludge landfill management is to control costs. Effective cost control requires timely recognition of excessive costs and the identification of the reason for such cost overruns. The increasing costs and complexities of sludge landfill operations require the use of more sophisticated cost control tools than have been used in the past. Use of cost accounting systems at landfills are recommended in order for management to control costs.

Because user fees are generally not charged at sludge landfills (reducing the need for accountability) and sludge landfills are usually administered by sewer departments and as such are not separate enterprises, but merely a secondary facet of a larger operation, cost records at most sludge landfills are either non-existent or poorly maintained.

The installation of a cost accounting system has several benefits, including [4]:

1. The system facilitates orderly and efficient accumulation and transmission of relevant data. Much of the recommended data is already being collected or should be. Hence, the added cost of installing the system is minimal.

2. The data can be grouped in standard accounting classifications. This simplifies interpretation of results and comparison with data from previous years or other operations, and in turn, allows analysis of relative performance and operational changes.

3. The system can account for all relevant costs of construction and operation.

4. Accumulated data from the system can, over a period of time, lead to standards of performance and efficiency that can be used to control costs by indicating which costs are high and the reasons for these costs. The supervisor of operations may then take corrective action.

5. The system includes automatic provisions for accountability. Cost control becomes more effective when the individual responsible for cost increases can be ascertained.

6. Use of the collected data aids in short- and long-range forecasting of capital and operating budgets. Future requirements for equipment, manpower, cash, etc., can be accurately estimated. This, in turn, aids planning at all levels of management. The data is also available for later evaluation and analysis.

7. The system can be flexible enough to meet the varying requirements of sludge landfills, of different sludge quantities and types, site conditions, and landfilling methods.

Generally landfill costs can be categorized into capital costs and operating costs. For the purposes of the accounting system recommended herein, capital costs are meant to include all non-recoverable initial expenses required prior to the start-up of operation. Capital costs usually include:

1. Land
2. Planning and design
3. Site preparation (i.e., clearing and grubbing, road construction, surface water/leachate controls, soil stockpiles, monitoring)
4. Facilities (i.e., offices, personnel shelters, garages, etc.)
5. Equipment purchase

Operating costs are expenses incurred during the on-going operation of the landfill and usually include:

1. Equipment fuel
2. Equipment maintenance and parts

3. Office/trailer rental
4. Supplies and materials
5. Utilities (i.e., electricity, heating oil, water, sewer, gas, telephone, etc.)
6. Laboratory analyses
7. On-going inspection and engineering

Costs may be computed on the basis of wet tons, dry tons, and cubic yards. Forms for compiling total and unit capital and operating costs based on wet tons have been included as Figures 9-5 and 9-6.

FIGURE 9-5

CAPITAL COST FORM
(Area Fill Mound Receiving 500 wet tons/day)

	Quantity	Unit Cost ($)	Total Cost ($)
Land	200 ac	2,500/ac	500,000
Site Preparation			
Clearing and grubbing	100 ac	705/ac	70,500
Sodded diversion ditch	6,261 ft	2.50/LF	15,652
Sodded runoff ditch	6,261 ft	2.50/LF	15,652
Pond	7	7,500/ea	52,500
Monitoring wells	4	300/ea	1,200
Soil stockpiles	1,247,083 yd^3	2.55/yd^3	3,180,062
Garage (40 x 80)	3,200 ft^2	15.00/ft^2	48,000
Gravel Roads	4,500 ft	1.85/LF	8,325
Asphalt Roads	750 ft	3.35/LF	2,512
Miscellaneous	--	--	--
Equipment			
Cat D-4 dozer	1	41,760	41,760
Cat D-6 dozer	1	60,020	60,620
Cat 941 track loader	1	39,680	39,680
Cat 955 track loader	1	52,730	52,730
Cat 930 wheel loader	1	36,972	36,972
Cat 621 scraper	1	144,250	144,250
Cat 930 backhoe	1	46,955	46,955
Subtotal			4,317,370
Engineering @ 6%			259,042
TOTAL			4,576,412
Amortized @ 7% for 5 years			1,116,141
Total Annualized Cost	$1,116,141 ÷ 182,500 tons = $6.12/wet ton		

1 ton = 0.907 Mg
1 ac = 0.405 ha

FIGURE 9-6

OPERATING COST FORM
(Area Fill Mound Receiving 500 wet tons/day)

	Quantity (per year)	Unit Cost ($)	Total Cost ($)
Labor (10 men)	29,200 M-H	8.00/hr	233,600
Equipment Fuel, Maintenance & Parts			
1 - Cat D-4 dozer	2,920 hrs	4.50/hr	13,140
1 - Cat D-6 dozer	1,460 hrs	8.37/hr	12,220
1 - Cat 941 track loader	2,190 hrs	5.45/hr	11,935
1 - Cat 955 track loader	2,920 hrs	8.98/hr	26,222
1 - Cat 930 wheel loader	2,190 hrs	7.35/hr	16,096
1 - Cat 621 scraper	1,460 hrs	21.88/hr	31,945
1 - Cat 930 backhoe	2,920 hrs	8.15/hr	23,798
Office Trailer Rental	3 ea	3,720/ea	11,160
Utilities	--	--	15,000
Lab Analyses	--	--	6,000
Supplies & Materials	--	--	50,000
Engineering	--	--	--
Miscellaneous	--	--	20,000
TOTAL	$471,116 ÷ 182,500 tons = $2.58/wet ton		

1 ton = 0.907 Mg

9.7 Financing

The management of a sludge landfill involves two basic financial decisions: (1) How should the capital requirements be financed? and (2) How should the operating costs be financed? These decisions are influenced largely by whether the landfill is a public or private operation. Certain methods of financing are available only to public operations: general funds, general obligation borrowing, revenue bonds, sewer rate increases or special assessments, and grants and subsidies. Other methods of financing are available to both public and private operations: loans and user fees. A description of each of these financing methods follows below.

9.7.1 General Funds

The general fund is derived from taxes. Although it normally cannot provide enough money to meet capital costs, it is often used to pay for operating expenses [3]. There are advantages to using the general fund for this purpose. The administrative procedures and extra cost of billing and collecting fees from contributing treatment plant authorities are eliminated. Using general funds for sludge landfills does, however, have disadvantages. Cost accounting and other administrative procedures may be so relaxed that disposal costs may be difficult or impossible to determine. It may also be extremely difficult for sludge landfill operations to get money from the general fund because of the low priority often assigned to them.

9.7.2 General Obligation Borrowing

General obligation borrowing is one method of financing the capital costs of a sludge landfill. This type of bond generally carries a low interest rate but is easily marketed because it is secured by the pledge of real estate taxes and because all of the real estate within the taxing district serves as security for the borrowed funds. State statutes usually limit the amount of debt a community can incur. If the debt is already substantial, this method may not be available. In some cases, general obligation bonds are retired with revenues generated by the sludge landfill; this minimizes the ad valorem taxes necessary for bond retirement.

9.7.3 Revenue Bonds

Revenue bonds differ from general obligation bonds in that they are secured only by the ability of the project to earn enough to pay the interest and principals. In this case, fees must be charged to users of the sludge landfill in amounts necessary to cover all capital and operating expenses. Fees should be high enough to accumulate a surplus over and above debt service needs in order to make the bonds attractive to prospective purchasers. This method of financing requires that the administering agency follow good cost accounting procedures, and it allows the agency to be the sole beneficiary of cost saving procedures. In addition, sewer authorities contributing sludge to the landfill are forced to pay the true cost of its disposal.

9.7.4 Sewer Rate Increases or Special Assessments

When the sludge landfill is owned and operated by the sewer authority, sewer rate increases or special assessments are the usual method of financing both the capital and operating costs of the facility. If strong opposition at a local level arises due to proposed increases in sewer rates or special assessments, a public education program might be in order to gain support for the additional charge.

9.7.5 Grants or Subsidies

Sludge management systems may be eligible for various Federal, state, or local funding. Sludge landfills are often eligible for grants from the EPA Construction Grants Program administered by the Office of Water Program Operations. These grants may cover a significant portion (up to 75%) of the capital fundings for the entire sludge management system including land aquisition, equipment purchase, and site preparation [5]. In codisposal sites, or in sites that handle industrial sludges, the amount of funding will be prorated based on what percentage of the total waste processed at the site is municipal sludge. The funding received in grants or subsidies is generally for the entire sludge management system, including sludge processing systems at the treatment plant as well as disposal systems. All of the operating costs and some of the capital costs must be financed from other sources. Despite the large percentage of the total cost which may remain after grants or subsidies have been exhausted, this contribution may be essential in enabling local governments to finance such systems as they become even more costly.

9.7.6 Loans

Loans from commercial institutions are often used to finance the capital costs of constructing sludge landfills. Thereafter, user fees can be used to accommodate operating costs and to gradually pay off the debt incurred in construction. Accordingly, user fees should be set sufficiently high to pay operating costs and to repay the loan. In addition, a portion of user fees should be set aside to help finance the ultimate use of the site and also capital construction of future sludge landfill sites.

9.7.7 User Fees

When the sludge landfill is privately owned and operated, user fees are the normal financing method. The private operation charges the contributing sewer authority for disposing sludge. Alternatively, user fees might be employed by a publicly owned and operated landfill if more than one sewer authority contributes sludge. Sometimes, user fees are employed when the landfill is publicly owned and receives sludge from only one sewer authority. For example, a public works department operating a sludge landfill may choose to finance its operation by charging the sewer department for the sludge disposed.

User fees are primarily a source of operating revenue, but a municipality might also employ them to generate funds for future capital expenditures such as preparing the final site and/or purchasing future sites. However, it should be noted that fees do not usually provide the capital outlay needed to start a sludge landfill.

Although fees necessitate a greater management expense due to the increased recordkeeping required, these records provide a basis for cost conscious management and operation of the landfill.

9.8 Typical Costs

This section presents typical costs for sludge hauling and landfilling. Cost curves are presented in terms of cost per wet ton vs. sludge quantity received. Typical costs are presented for (1) sludge hauling, (2) annualized site capital costs, (3) site operating costs, and (4) total site costs (combined annualized capital and operating).

These curves can be useful in the early stages of sludge landfill planning. However, typical costs should be used only in preliminary work. Actual costs vary considerably with specific sludge and site conditions. Therefore, use of these curves for computing specific project costs is not recommended. Site-specific cost investigations should be made in each case.

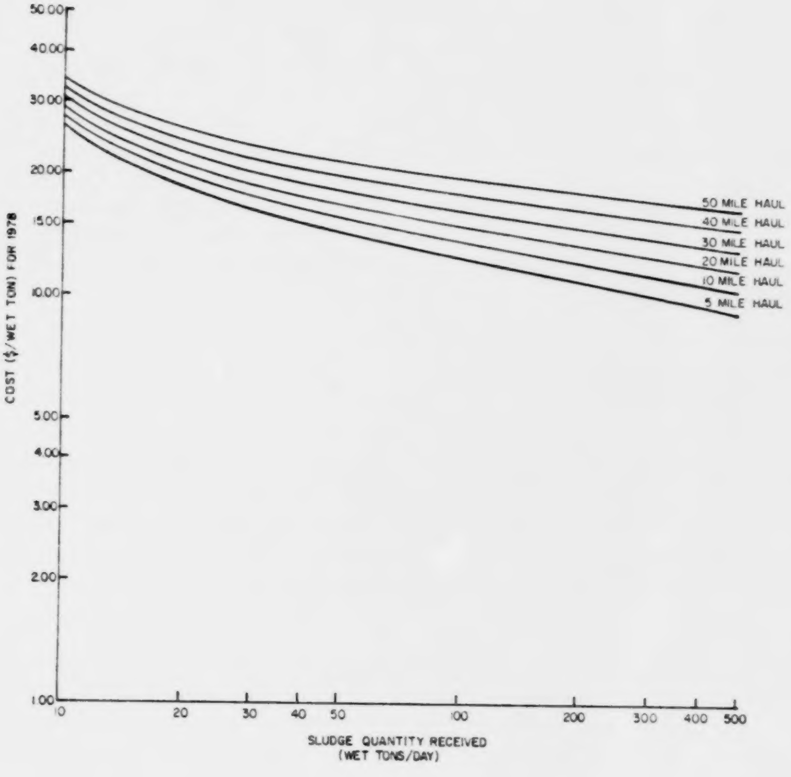
9.8.1 Hauling Costs

Typical costs for hauling wastewater treatment sludge are presented in Figure 9-7. As shown, costs are given in dollars per wet ton as a function of the wet tons of sludge delivered to the site each day. Costs are presented for alternative distances of 5, 10, 20, 30, 40, and 50 mi (8.0, 16.1, 32.2, 48.3, 64.4, and 80.4 km) hauls.

"Principals and Design Criteria for Sewage Sludge Application on Land" [6] and "Transport of Sewage Sludge" [7] were the primary sources of information for data and procedures in developing these hauling costs. Other references [8][9][10] are available and were also consulted and utilized. Sludge hauling costs were originally prepared for the year 1975 but were updated to reflect 1978 costs.

FIGURE 9-7

TYPICAL HAULING COSTS



The hauling costs shown in Figure 9-7 reflect not only transportation costs, but also the cost of sludge loading and unloading facilities. For a plant producing approximately 10 wet tons (9.1 Mg) per day of a dewatered sludge and a 5-mi (8.0-km) haul, sludge loading and unloading facilities were found to contribute 60% of the total hauling costs. For a plant producing approximately 250 wet tons (227 Mg) per day of dewatered sludge and a 40 mi (64.4 km) haul, loading and unloading facilities contributed less than 10% of the total hauling costs.

Because of the differing bases for cost computations, certain assumptions on sludge volumes and unit costs were utilized to produce the hauling cost curve. These assumptions include:

1. The sludge was dewatered and had a solids content of approximately 20%. It was hauled by a 15 yd^3 (11.5 m^3), 3-axle dump truck.
2. Hauling was performed 8 hrs per day, 7 days per week.
3. Fuel cost was \$0.60 per gal (\$0.16 per 1).
4. Labor (primarily truck driving) cost were \$8.00 per hr including fringe benefits.
5. Overhead and administrative costs were 25% of the operating cost.
6. Capital costs were annualized. A rate of 7% over 6 years was used for the trucks with a salvage value of 15%. A rate of 7% over 25 years was used for loading and unloading facilities with no salvage value.

If conditions other than the above-stated conditions prevail at a given site, the hauling costs in Figure 9-7 should be revised upward or downward appropriately. As an example, if 10 yd^3 (7.6 m^3) 2-axle dump trucks are used, costs should be higher by factors ranging from 1.3 for a plant generating 250 wet tons (227 Mg) per day with a 50-mi (80 km) haul to 1.0 for a plant generating 10 wet tons (9.1 Mg) per day with a 5-mi (8.0 km) haul. Alternatively, if a 30 yd^3 (23.9 m^3) dump truck is used, costs should be lower by factors ranging from 0.6 to 1.0 for the aforementioned sludge quantities and haul distances.

9.8.2 Site Costs

Typical site costs for landfilling wastewater treatment sludges are presented in Figure 9-8, 9-9, and 9-10. As shown, costs are given in dollars per wet ton of sludge received as a function of the wet tons of sludge delivered to the site each day. Costs are presented for each of the alternative landfilling methods. Scenarios using average design dimensions and application rates were devised for the purposes of these cost calculations. These scenarios are summarized in Table 9-1. The cost curve for each method was plotted from computations which assumed alternative quantities of 10, 100, and 500 wet tons (9.1, 90.7, and 453 Mg) of sludge for each scenario.

Capital costs are summarized in Figure 9-8. Capital cost items included:

1. Land
2. Site preparation (clearing and grubbing, surface water control ditches and ponds, monitoring wells, soil stockpiles, roads, and facilities)
3. Equipment purchase
4. Engineering

Capital costs were then annualized at 7% interest over 5 years (the life of the site) and divided by the sludge quantity delivered to the site in one year.

FIGURE 9-8

TYPICAL SITE CAPITAL COSTS FOR SLUDGE LANDFILLING

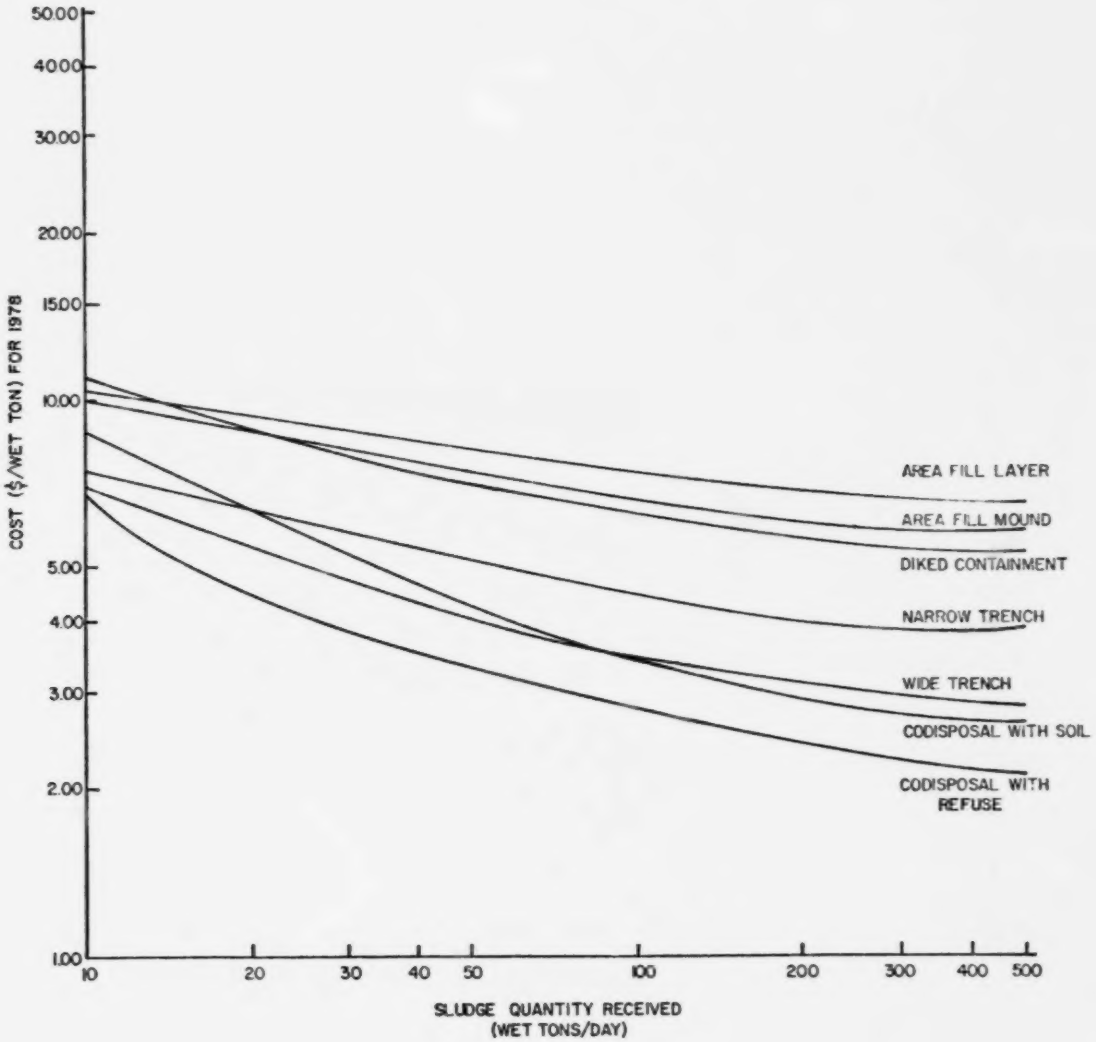


FIGURE 9-9

TYPICAL SITE OPERATING COSTS
FOR SLUDGE LANDFILLING

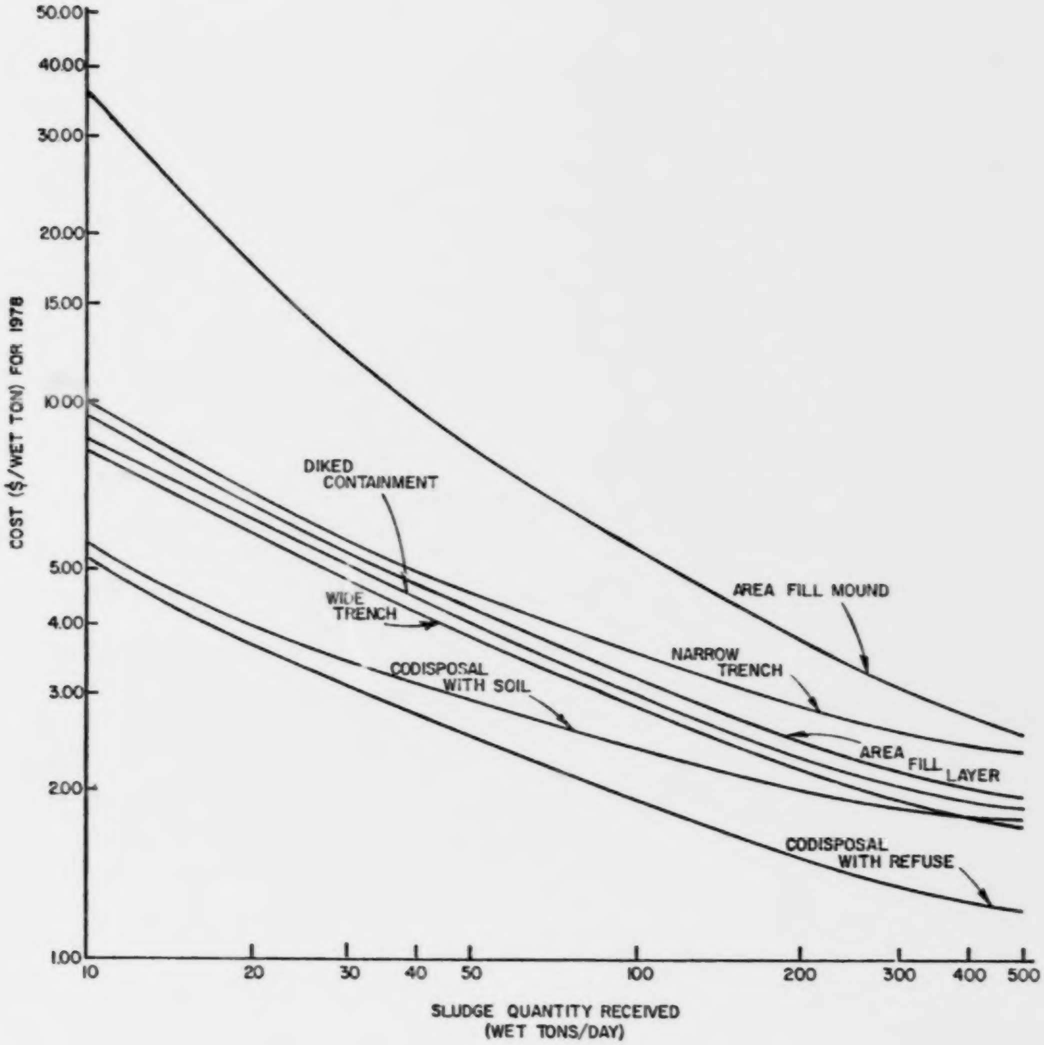


FIGURE 9-10

TYPICAL TOTAL SITE COSTS FOR SLUDGE LANDFILLING
(COMBINED CAPITAL AND OPERATING COSTS)

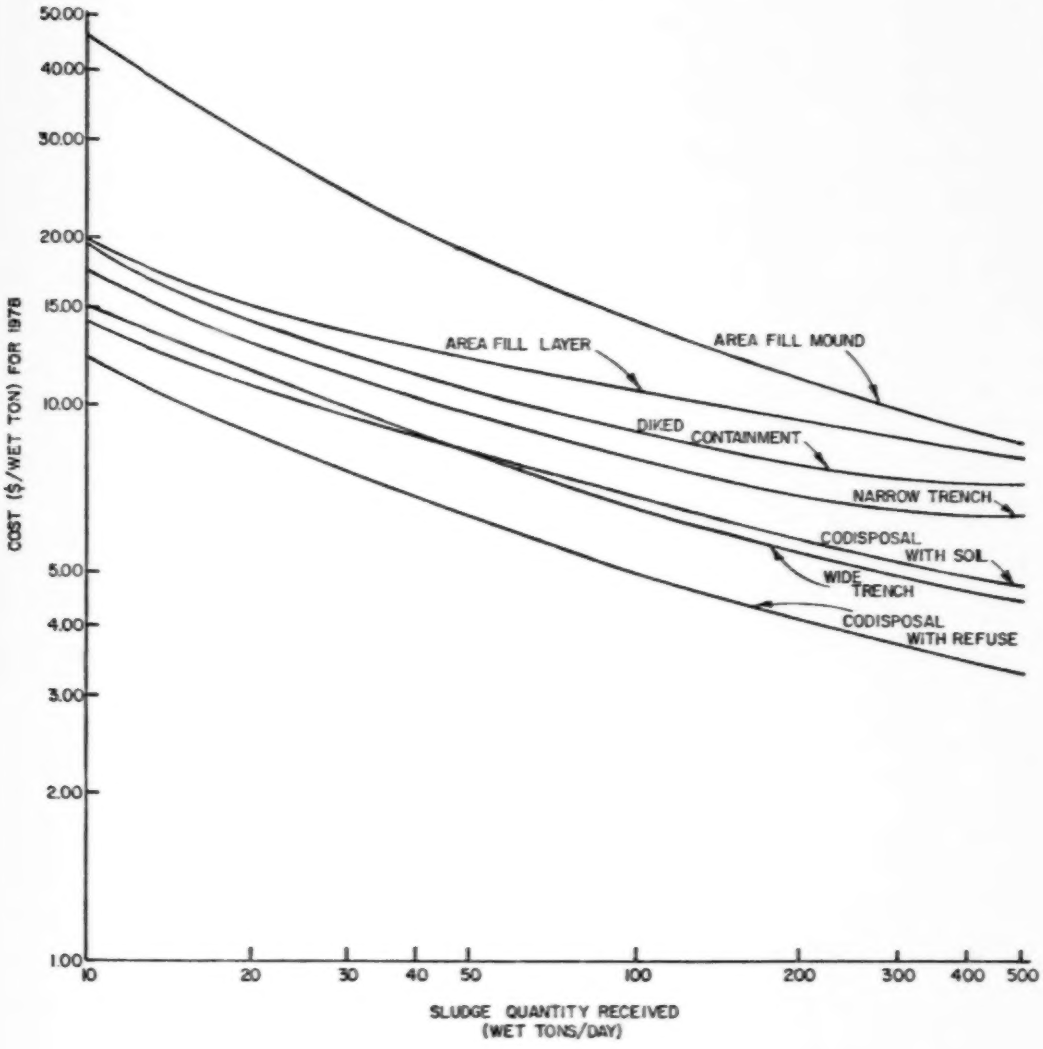


TABLE 9-1

COST SCENARIOS FOR ALTERNATIVE LANDFILLING METHODS

Identification			Site Preparation				Sludge Bulking			Sludge Filling			Sludge Covering			Miscellaneous	
Scenario No.	Landfilling method	Sludge Solids Content (%)	Width (ft)	Depth (ft)	Length (ft)	Spacing (ft)	Bulking Performed	Bulking agent	Bulking ratio (bulking agent: sludge)[a]	Sludge depth per lift (ft)	No. of lifts	Sludge application rate (yd^3/acre)	Cover applied	Cover Thickness Interim (ft)	Cover Thickness Final (ft)	Imported soil required	Primary equipment
1	Narrow trench[a]	22	6	6	100	9	No	--	--	4	1	2,500	Yes	—	4	No	Backhoe with loader, track dozer, excavator
2	Wide trench[b]	32	60	8	600	30	No	--	--	4	1	4,100	Yes	—	5	No	Track loader, scraper, track dozer
3	Area fill mound[b]	30	—	—	—	—	Yes	Soil	1:1	6	2	9,680	Yes	3	1	Yes	Track loader, backhoe, track dozer, scraper, wheel loader
4	Area fill layer[b]	30	—	—	—	—	Yes	Soil	0.5:1	2	2	4,300	Yes	0.5	1	Yes	Track dozer, scraper, grader, wheel loader
5	Diked containment[a]	25	50	30	100	30	Yes	Soil	0.5:1	6	4	12,410	Yes	1	3	Yes	Dragline, track dozer, scraper
6	Sludge/refuse[b] mixture	20	—	—	—	—	Yes	Refuse	7 tons:1 wet ton	6	3	2,520	Yes	0.5	2	No	Track dozer, truck loader
7	Sludge/soil[b] mixture	20	—	—	—	--	Yes	Soil	1:1	1	1	1,600	No	—	—	No	Tractor with disc, grader, track loader

1 ft = 0.305 m
1 yd^3 = 0.765 m^3
1 acre = 0.405 ha

[a] Land-based

[b] Sludge-based

Operating costs are summarized in Figure 9-9. Operating cost items included:

1. Labor
2. Equipment fuel, maintenance and parts
3. Utilities
4. Laboratory analysis of water samples
5. Supplies and materials
6. Miscellaneous and other

Operating costs (see Figure 9-9) for one year were then divided by the annual sludge quantity delivered to the site.

The costs shown, which were derived from a variety of published information sources [11][12][13] and case study investigations, have been revised upward to reflect 1978 prices. Several assumptions were employed in producing these cost curves. These assumptions include:

1. Life of the landfill site was 5 years
2. Land cost was $2,500 per acre ($6,177 per ha)
3. Actual fill areas (including inter-trench spaces) consumed 50% of the total site area
4. Engineering was 6% of the total capital cost
5. Operating labor cost $8.00 per hour including fringe, overhead, and administration

It should be noted that the site costs shown for codisposal operations were derived by dividing the additional annualized capital cost and additional operating cost by the sludge quantity received. Actual unit costs for typical refuse landfills not receiving sludge may be expected to be less.

9.8.3 Cost Analysis

As stated previously, these cost curves should not be used for site-specific cost compilations performed during design. However, they can be useful in the preliminary planning stages of a specific sludge landfill. In addition, they are useful in developing some general conclusions about sludge landfill costs. For instance, cost ranges included:

1. Hauling costs ranged from \$8.80 per wet ton (\$9.70 per Mg) for a 5-mi (8.1-km) haul of 500 wet tons (453 Mg) per day to \$34.00 per wet ton (\$37.49 per Mg) for a 50-mi (80.4-km) haul of 10 wet tons (9.1 Mg) per day.

2. Annualized site capital costs ranged from \$2.20 per wet ton (\$2.43 per Mg) for a sludge/refuse codisposal operation receiving 500 wet tons (453 Mg) per day to \$10.10 per wet ton (\$11.11 per Mg) for a diked containment operation receiving 10 wet tons (9.1 Mg) per day.

3. Site operating costs ranged from \$1.20 per wet ton (\$1.32 per Mg) for a sludge/refuse codisposal operation receiving 500 wet tons (453 Mg) per day to \$36.10 per wet ton (\$39.80 per Mg) for an area fill mound operation receiving 10 wet tons (9.1 Mg) per day.

4. Combined site costs ranged from \$3.40 per wet ton (\$3.75 per Mg) for a sludge/refuse codisposal operation receiving 500 wet tons (453 Mg) per day to \$46.20 per wet ton (\$50.94 per Mg) for an area fill mound operation receiving 10 wet tons (9.1 Mg) per day.

Also, an assessment can be made of the relative costs of alternative landfilling methods. A prioritized list of landfilling methods is based on total site costs (see Figure 9-10) with lowest costs first is as follows:

1. Codisposal with sludge/refuse mixture
2. Wide trench
3. Codisposal with sludge/soil mixture

4. Narrow trench
5. Diked containment
6. Area fill layer
7. Area fill mound

The cost of a landfilling method is determined by the efficiency of the operation in terms of manpower, equipment, and land use. Other factors, such as haul distances play a role in the cost effectiveness of a given site but are the same for the various methods.

As indicated, codisposal and wide trench methods tend to be the most economical landfilling methods. Codisposal operations tend to be larger and benefit from the economies of scale. In addition, the availability of "free" bulking material in the form of refuse reduces labor costs. Wide trenches have high application rates and are land and labor efficient. It should be noted however, that the relatively high solids content required for effective utilization of wide trenches will increase the cost of sludge handling at the treatment plant.

Narrow trenches have relatively higher labor requirements and are land intensive, contributing to high capital and operating costs. Area fill mounds, and layers are labor and equipment intensive.

Diked containment requires a relatively large operation before it becomes a cost-effective means of landfilling. This is a result of high initial labor and equipment requirements. Once established, however, diked containments are efficient in terms of operation and land use.

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CHAPTER 10

DESIGN EXAMPLES

10.1 Introduction

The design of a sludge landfill is highly dependent upon many sludge characteristics and site conditions, such as percent solids, climate, soil, topography, and others. Consequently, no design example can be universal. However, examples can be illustrative of the design and operating procedures which have been recommended in the preceding chapters.

This chapter contains three design examples. The approach in each of these examples is to present sludge characteristics and site conditions as given design data. The first example is for a large sludge landfill receiving 19% solids sludge from a municipal wastewater treatment plant serving a population equivalent of 200,000. In this example, the landfilling method is selected early in the design process, and the design proceeds to (1) determine design dimensions, (2) prepare site development plans, (3) determine equipment and personnel requirements, (4) develop operational procedures, and (5) estimate costs. The second example is for a sludge landfill receiving 29% solids sludge from a plant serving a population equivalent of 50,000. In this example, two alternative landfilling methods appear to be equally suitable at first. Alternate designs are performed for each before one method is selected on the basis of costs. The third design example is for a small plant serving a population equivalent of only 5,000. Plant management is faced with a choice between landfilling their 34% solids sludge at the treatment plant site or disposing it at an existing refuse landfill.

It should be noted that the scope of this chapter is confined to design only; i.e., it is assumed that the sites in the design examples have already been selected. An example of the site selection process was given in Chapter 4, Site Selection. It should also be noted that the design described in this chapter is somewhat preliminary in nature. A final designs should contain more detail and address other design considerations (such as sediment and erosion controls, roads, leachate controls, etc.) which are not fully addressed herein.

10.2 Design Example No. 1

10.2.1 Statement of Problem

The problem was to design a sludge-only landfill at the location of a pre-selected site. As stated previously, the landfill was to receive a 19% solids sludge from an existing municipal wastewater treatment plant serving a population equivalent of 200,000. The recommended design had to be (1) in compliance with pertinent regulations, (2) environmentally safe, and (3) cost-effective.

10.2.2 Design Data

The following information is included as given design data and was useful in executing the subsequent design.

10.2.2.1 Treatment Plant Description

The wastewater treatment plant was a secondary treatment facility. Further information on the facility is as follows:

1. Service population equivalent = 200,000
2. Average flow = 20 Mgal/d (0.86 m^3/sec)
3. Industrial inflow = 10% of total inflow
4. Wastewater treatment processes:
    a. bar screen separation
    b. aerated grit tanks
    c. primary settling tanks
    d. secondary aeration tanks
    e. secondary settling tanks

10.2.2.2 Sludge Description

Sludge was generated primarily by two sources (primary and secondary settling tanks). The sludge was stabilized and dewatered. A more complete description is as follows:

1. Sludge sources
    a. primary settling tanks
    b. secondary settling tnks
2. Sludge treatment
    a. gravity thickening
    b. mixing
    c. anaerobic digestion
    d. vacuum filtration

3. Sludge characteristics (based on testing, review of records, and calculations)

    a. Solids content = 19%
    b. Quantity on a dry weight basis = 13.0 dry tons/day (11.8 Mg/day)
    c. Quantity on a wet weight basis = 68.4 wet tons/day (62.0 Mg/day)
    d. Density = 1,700 lbs/yd^3 (1,009 kg/m^3)
    e. Quantity on a wet volume basis = 80.5 yd^3/day (61.6 m^3/day)

10.2.2.3 Climate

Significant climatological factors having an impact on sludge landfilling are listed below:

1. Precipitation = 32 in./yr (81 cm/yr)
2. Evaporation = 28 in./yr (71 cm/yr)
3. Number of days minimum temperature 32°F (0°C) and below = 60 days/yr

As shown, the climate was relatively mild with cold temperatures prevailing approximately two months per year. Precipitation exceeds evaporation by 4 in./yr (10 cm/yr).

10.2.2.4 General Site Description

Preliminary data was collected during the site selection process. It is summarized below:

1. Size of property = 375 acre (152 ha)
2. Property line frontage:

    a. 5,200 ft (1,580 m) along county road
    b. 4,700 ft (1,430 m) along residences
    c. 4,600 ft (1,400 m) along grazing land
    d. 1,200 ft (370 m) along woodland

3. Slopes: Uniform slope of approximately 5%
4. Vegetation:

    a. 225 acres (91 ha) of woodland
    b. 150 acres (60 ha) of grassland

5. Surface water: None on site

A plan view of the site is presented in Figure 10-1. As shown, the site had good access along a county road. The site was located in a moderately developed residential area and abuts residences. Approximately 60% of the site was covered with woodland. The balance of the property had been used for grazing and remained grass-covered.

10.2.2.5 Hydrogeology

Eight test borings were performed on the site to determine subsurface conditions. These were located as shown in Figure 10-1. Subsurface conditions generally were similar at all boring locations and can be summarized as follows:

Depth	Description
0-12 ft (0-3.7 m)	Silt loam
12-15 ft (3.7-4.6 m)	Saturated silt loam
>15 ft (>4.6 m)	Fractured crystalline rock

As can be seen above, groundwater was determined to be at a depth of 12 ft (3.7 m) and bedrock was at a depth of 15 ft (4.6 m). Samples of the silt loam were collected for analysis and the following determinations made:

1. Texture = medium
2. Permeability = 2 x 10^{-4} cm/sec
3. Permeability class = moderately slow
4. pH = 6.5
5. Cation exchange capacity (CEC) = 18 meq/100 g

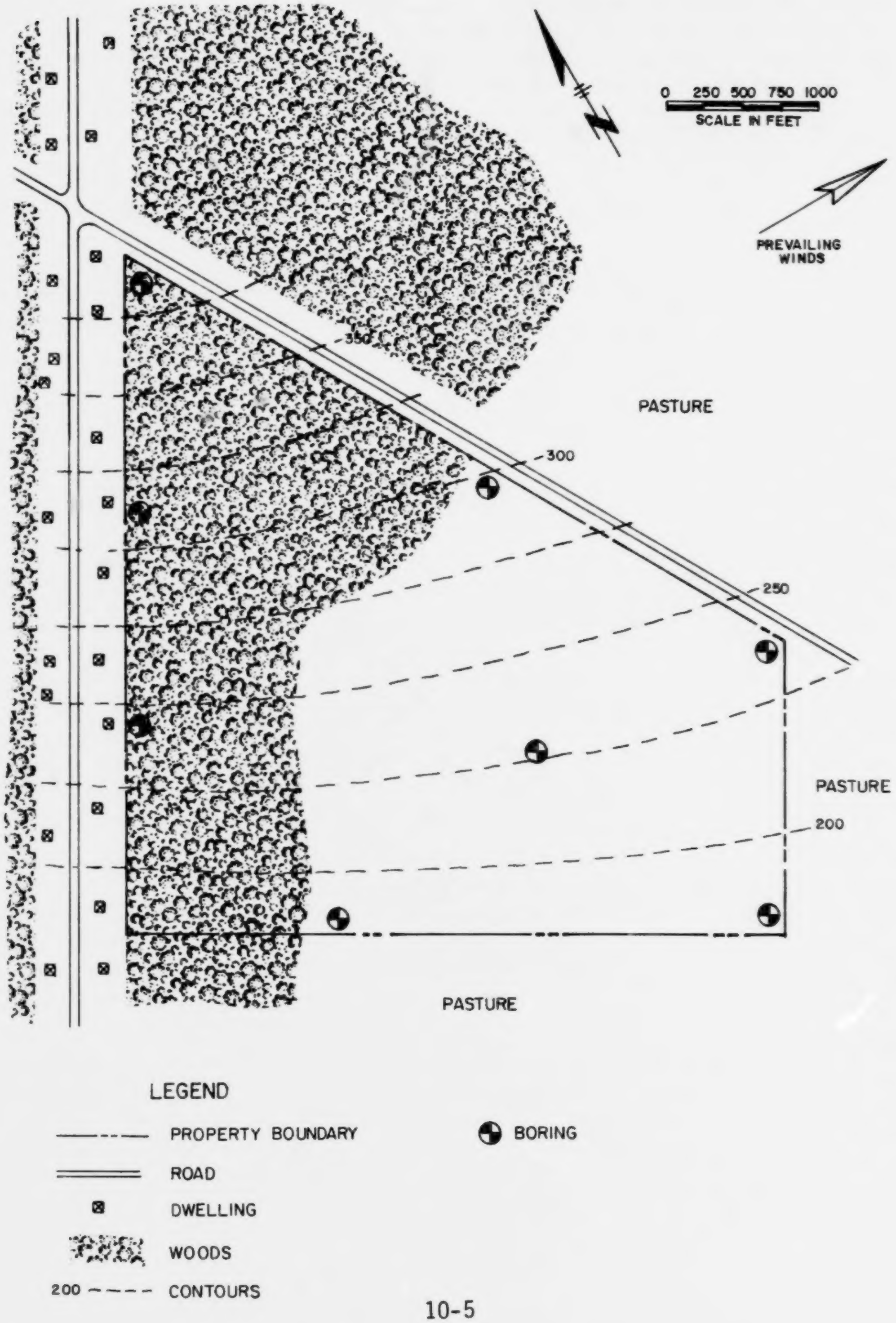
10.2.3 Design

10.2.3.1 Landfilling Method

Table 3-7 in Chapter 3 (Sludge Characteristics and Landfilling Methods) should be consulted as a reference. Since the sludge to be received is

FIGURE 10-1

SITE BASE MAP FOR EXAMPLE NO. 1



stabilized, it can be received by any of the five sludge-only landfilling methods shown in this table. Also, since the ground slope is relatively flat at 5%, any of these five methods are suitable. However, since the sludge has a solids content of 19%, only narrow trenches and area fill layers are suitable operations. Lastly, since groundwater and bedrock are relatively deep (at 12 and 15 ft (3.7 and 4.6 m), respectively), a narrow trench operation should be employed. Because the solids content of the sludge is between 15 and 20%, cover application should be via land-based equipment as shown in Table 3-8. Soil should be used primarily for cover and is not required for bulking.

10.2.3.2 Design Dimensions

Table 5-5 in Chapter 5 (Design) should be consulted as a reference. As shown in this table, the design dimensions to be determined for any trench operation include the following:

1. Excavation depth
2. Spacing
3. Width
4. Length
5. Orientation
6. Sludge fill depth
7. Cover thickness

The excavation depth is determined initially by the depth to groundwater or bedrock. A minimum separation of 2 to 5 ft (0.6 to 1.5 m) is usually provided between sludge deposits and the top of bedrock or groundwater. In this case, a separation of 4 ft (1.2 m) was selected. The soil pH of 6.5 means a slightly higher than average opportunity for contaminant movement since contaminants move somewhat more readily in an acidic soil. However, the permeability was classified as "moderately slow" and the CEC was relatively high at 18 meq/100 g. Thus, containment and attenuation were seen as sufficient with a 4 ft (1.2 m) separation. Since groundwater is at a depth of 12 ft (3.7 m) and is shallower than bedrock, a 4 ft (1.2 m) separation dictates an excavation to 8 ft (2.4 m). Trench spacing is determined chiefly by sidewall stability. As a general rule, 1.0 to 1.5 ft (0.30 to 0.46 m) of spacing provided for every 1 ft (0.3 m) of trench depth. Since the soil type was found to be relatively stable, 1.0 ft (0.3 m) of spacing for every 1 ft (0.3 m) of trench depth was suspected to be adequate and a total spacing of 8 ft (2.4 m) was held.

Trench width is determined by sludge solids content and equipment considerations. Since the sludge is only 19% solids, a 2 to 3 ft (0.6 to 0.9 m) width should be used. Normally, when the sludge solids content is less than 20%, cover applied atop the sludge would sink to the bottom. However, at a width of 2 to 3 ft (0.6 to 0.9 m) the cover soil creates a bridging effect over the sludge receiving its support from solid ground on either side of the trench. A backhoe was selected as the most efficient piece of equipment for excavations to an 8 ft (2.4 m) depth. Subsequently, a 2 ft (0.6 m) width was specified based on the equipment efficiency of the backhoe. The length for narrow trenches is limited only by the need to place containment within the trench to prevent low-solids sludge from flowing to one end of a trench. Trench length was set at 200 ft (61 m). Thus, at every 200 ft (61 m) the trench was discontinued for 5 ft (1.5 m) to provide containment. With regard to trench orientation, trenches should be kept parallel to one another to optimize land utilization. Because of the relatively flat slopes at the site, it was not found necessary to orient the trenches parallel to topographic contours.

As shown in Table 5-5, for trench widths between 2 and 3 ft (0.6 and 0.9 m), the sludge fill depth should be to within 1 to 2 ft (0.3 to 0.6 m) of the ground surface. Because the excavation depth is greater than usual for a trench of this width, it was decided that sludge filling should proceed no closer than 2 ft (0.6 m) from the top. Cover application for a 2 ft (0.6 m) wide trench should be from 2 to 3 ft (0.6 to 0.9 m) thick. This thickness was held at 3 ft (0.9 m) due to the large sludge fill depth.

In order to test the practicality of these design dimensions, a full-scale test was performed at the site. Initially, a backhoe was used to excavate two parallel trenches at the previously-specified depth, width, and spacing. A 10 yd^3 (7.6 m^3) dump truck (to be used in sludge hauling) was then fully loaded with sludge and backed up to the trench. Since the trench sidewall withstood the load, the prescribed trench depth, width, and spacing were found to be sound. Subsequently, the sludge load was dumped into the trench, filling it to a 6 ft (1.8 m) depth. Three ft (0.9 m) of cover was then gently applied over the sludge by the backhoe. The cover was found to be adequately supported at the time. At an inspection of the test trenches several weeks later no sludge had emerged. However, the cover had settled almost 1 ft (0.3 m). Since this settlement could cause ponding of rainwater over settled trenches in the future, the cover application thickness was increased to a total of 4 ft (1.2 m) or to 2 ft (0.6 m) above grade. The design was then able to proceed based on the following design dimensions:

1. Excavation depth = 8 ft (2.4 m)
2. Spacing = 8 ft (2.4 m)
3. Width = 2 ft (0.6 m)
4. Length = 200 ft (61 m)
5. Orientation = trenches parallel to each other but not necessarily parallel to contours
6. Sludge fill depth = 6 ft (1.8 m)
7. Cover thickness = 4 ft (1.2 m)

10.2.3.3 Site Development

Site development was in accordance with the plan shown in Figure 10-2. Features of this plan included the following:

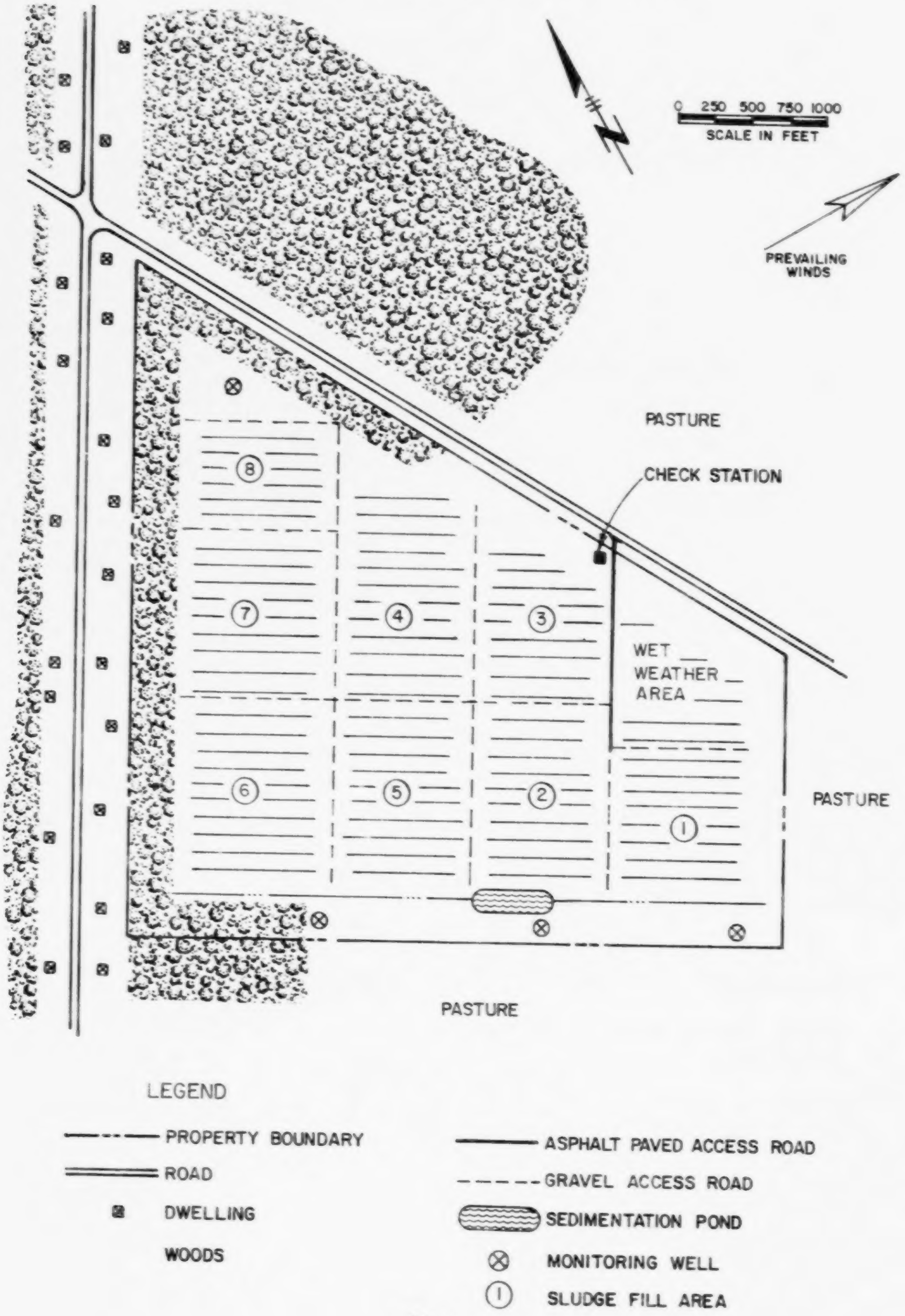
1. A 300 ft (91 m) wooded buffer was maintained between the sludge fill area and residences. A 200 ft (61 m) buffer was maintained around the balance of the property.
2. Trenches were installed along the downhill (southeastern) property line to collect storm water runoff. A sedimentation pond was constructed to receive runoff collected by these trenches
3. In accordance with State regulations and engineering judgement, one groundwater monitoring well was located upgradient from the fill area and three monitoring wells were located down-gradient from the fill area.
4. The site was divided into nine fill areas so that the site could be cleared in phases. In this way, clearing could proceed approximately once each year in advance of sludge filling operations.
5. The fill area located nearest to the site entrance was designated for wet weather operations. The access road to this area was paved with asphalt.
6. The remaining access roads were covered with gravel.
7. After providing area for buffers, access roads, facilities, etc. approximately 156 acres (63 ha) remained as usable fill area out of the entire 375 acres (152 ha) on the site.

10.2.3.4 Calculations

Based on the design data and dimensions stated previously, calculations can then be made of the (1) trench utilization rate, (2) sludge application rate, (3) land utilization rate, and (4) site life.

FIGURE 10-2

SITE DEVELOPMENT PLAN FOR EXAMPLE NO. 1



1. Trench utilization rate

$$= \frac{\text{sludge volume per day}}{\text{cross-sectional area of sludge in trench}}$$

$$= \frac{\text{sludge volume per day}}{(\text{trench fill depth}) \times (\text{trench width})}$$

$$= \frac{(80.5\ \text{yd}^3/\text{day}) \times (27\ \text{ft}^3/\text{yd}^3)}{(6\ \text{ft}) \times (2\ \text{ft})}$$

$$= 181\ \text{ft/day}\ (55.2\ \text{m/day})$$

2. Sludge application rate

$$= \frac{\text{cross-sectional area of sludge in trench}}{\text{width of trench + spacing}}$$

$$= \frac{(6\ \text{ft}) \times (2\ \text{ft})}{(2\ \text{ft}) + (8\ \text{ft})} = \frac{12\ \text{ft}^2}{10\ \text{ft}} = \frac{12\ \text{ft}^3}{10\ \text{ft}^2}$$

$$= \frac{(12\ \text{ft}^3)(1\ \text{yd}^3/27\ \text{ft}^3)}{(10\ \text{ft}^2)(1\ \text{acre}/43{,}560\ \text{ft}^2)}$$

$$= 1{,}936\ \text{yd}^3/\text{acre}\ (3{,}659\ \text{m}^3/\text{ha})$$

3. Land utilization rate

$$= \frac{\text{sludge volume per day}}{\text{sludge application rate}}$$

$$= \frac{80.5\ \text{yd}^3/\text{day}}{1{,}936\ \text{yd}^3/\text{acre}}$$

$$= 0.0416\ \text{acres/day}\ (0.0168\ \text{ha/day})$$

4. Site life

$$= \frac{\text{usable fill area}}{\text{land utilization rate}}$$

$$= \frac{156\ \text{acres}}{0.0416\ \text{acres/day}} = \frac{3{,}750\ \text{days}}{365\ \text{days/year}}$$

$$= 10.3\ \text{years}$$

10.2.3.5 Equipment and Personnel

Table 6-4 in Chapter 6 (Operation) should be consulted as a reference. As shown, for a narrow trench operation receiving between 50 and 100 wet tons per day (45 and 91 Mg per day) the following equipment might be selected:

Description	Quantity	Hours per Week
Track backhoe with loader	1	49
Track dozer	1	15
Total	2	64

The use of a backhoe was already established during the selection of design dimensions. Therefore, the above suggested scheme was implemented. The duties and number of personnel were also established at this stage and included:

Description	Quantity	Hours per Week
Backhoe operator	1	40
Backhoe and dozer operator	1	40
Total	2	80

Operations are conducted at the site 8 hours per day and seven days per week to coincide with sludge deliveries and avoid the added cost and odors often encountered with sludge storage facilities. The backhoe is operated seven hours per day (plus one hour downtime per day for routine maintenance and cleanup) and seven days per week. The dozer is operated three hours per day (plus one hour downtime per day for routine maintenance and cleanup) and five days per week. One full-time operator works 8 hours per day Monday through Friday. He is responsible for operating and maintaining the backhoe during these hours. The other operator works 8 hours per day Wednesday through Sunday; he is responsible for (1) operating and maintaining the backhoe for eight hours each day on Saturday and Sunday, (2) operating and maintaining the dozer for four hours each day on Monday through Friday, and (3) performing miscellaneous functions such as check station attendant, compiling site records, etc.

10.2.3.6 Operational Procedures

Site preparation consisted of the following procedures:

1. Initially, fill area no. 1 and the inclement weather area were cleared and grubbed. Roads providing access to these areas were paved with asphalt or gravel (as shown in Figure 10-2). Several trenches were excavated in the inclement weather area and the spoil stockpiled alongside each trench. Runoff, erosion, and sedimentation controls as well as monitoring wells were installed.

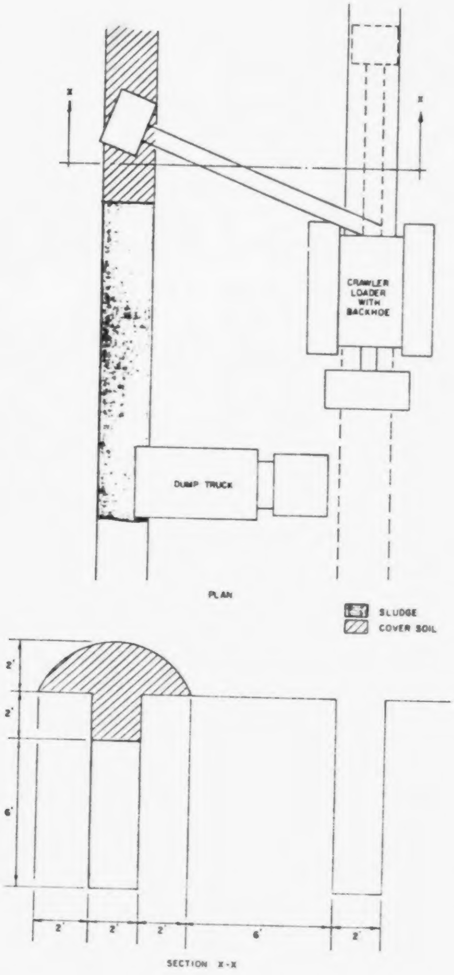
2. At least one month (but never more than four months) in advance of the fill operation, each new fill area is cleared and grubbed. Usually these operations occur once each year and are timed to avoid cold temperatures and frozen ground conditions. The work is performed by equipment and personnel brought in specifically for this task. Debris is disposed of on-site by burial and/or by producing wood chips.

On-going operations consist of the following:

1. Trenching begins in the corner of each fill area furthest removed from the access road and proceeds generally toward the road as it is completed.
2. Approximately 200 ft (61 m) of trench length is prepared in advance of the filling operation. This provides contingency capacity for slightly more than one day's sludge receipt.
3. Trenches are excavated to design dimensions by the track backhoe as it straddles the excavation (see Figure 10-3).

FIGURE 10-3

OPERATIONAL PROCEDURES FOR EXAMPLE NO. 1



4. Haul vehicles back-up to the previously excavated trench and dump sludge loads directly into the trench. Filling proceeds to approximately 2 ft (0.6 m) below the top of the trench. Because of its low solids content, sludge flows evenly throughout the trench and accumulations at one location are minimized.
5. Within one hour after sludge-filling has occurred in one location, the track backhoe excavates a new trench adjacent to the filled trench. Excavated material from the new trench is applied as cover over the adjacent sludge-filled trench. The cover is applied carefully from a low height at first to minimize the amount of cover sinking into sludge deposits. Subsequently, cover is applied less carefully. Ultimately the cover extends to 2 ft (0.6 m) above grade.

Site completion consists of the following procedures:

1. Approximately one-month after completion of each 1-acre (0.405 ha) portion of the landfill, the bulldozer is used to regrade the area to a smooth ground surface.
2. Immediately thereafter the site is hydroseeded (assuming weather conditions permit) and grasses soon take root.

10.2.3.7 Cost Estimates

Based on the site design, cost estimates were prepared for capital and operating costs in Tables 10-1 and 10-2, respectively. As shown, the total capital cost of the site was estimated at $1,186,421. If this cost is amortized at 7% interest over 10 years (the approximate life of the site), the annual cost is $168,923. Considering a site capacity of 260,000 wet tons (236,000 Mg) of sludge, the capital cost is $0.65 per wet ton ($0.72 per Mg).

As shown in Table 10-2, the annual operating cost was estimated at $89,413. Considering an annual receipt of 25,000 wet tons (22,700 Mg) of sludge, the unit operating cost is $3.58 per wet ton ($3.95 per Mg). Combined capital and operating costs were estimated at $4.23 per wet ton ($4.67 per Mg).

TABLE 10-1

ESTIMATE OF TOTAL SITE CAPITAL COSTS FOR EXAMPLE NO. 1

Item	Quantity	Unit Cost	Total Cost
Land	375 acres	$ 2,500/acre	$ 937,500
Site Preparation			
Clearing and Grubbing	45 acres	$ 705/acre	$ 31,725
Sodded Runoff Ditch	4000 ft	$ 2.50/acre	$ 10,000
Pond	1 ea	$15,000/ea	$ 15,000
Monitoring Wells	4 ea	$ 300/ea	$ 1,200
Garage	1600 ft^2	$ 15/ft^2	$ 24,000
Gravel Roads	1500 ft	$ 1.85/ft	$ 2,775
Asphalt Roads	1000 ft	$ 3.35/ft	$ 3,350
Miscellaneous	---	---	$ 5,000
Equipment			
Backhoe	1 ea	$46,955	$ 46,955
Dozer	1 ea	$41,760	$ 41,760
Subtotal	---	---	$ 1,119,265
Engineering @ 6%	---	---	$ 67,156
Total	---	---	$ 1,186,241

1 acre = 0.405 ha
1 ft = 0.305 m

TABLE 10-2

ESTIMATE OF ANNUAL OPERATING COSTS FOR EXAMPLE NO. 1

Item	Quantity	Unit Cost	Total Cost
Labor			
Backhoe Operator	2,080 hrs	$ 8.00/hr	$16,640
Backhoe/Dozer Operator	2,080 hrs	$ 8.00/hr	$16,640
Equipment Fuel, Maintenance and Parts			
Backhoe	2,555 hrs	$ 6.88/hr	$17,578
Dozer	780 hrs	$ 4.50/hr	$ 3,510
Clearing and Grubbing	10 acres	$ 705/acre	$ 7,050
Gravel Roads	1,500 ft	$ 1.85/ft	$ 2,775
Officer Trailer Rental	1 ea	$3,720/ea	$ 3,720
Utilities	--	--	$ 2,000
Laboratory Analyses	--	--	$ 2,500
Supplies and Materials	--	--	$12,000
Miscellaneous	--	--	$ 5,000
Total	--	--	$89,413

1 acre = 0.405 ha
1 ft = 0.305 m

10.3 Design Example No. 2

10.3.1 Statement of Problem

The problem was to design a sludge-only landfill at the location of a pre-selected site. As stated previously, the landfill was to receive a 29% solids sludge from a proposed municipal wastewater treatment plant serving a population equivalent of 50,000. The recommended design had to be (1) in compliance with pertinent regulations, (2) environmentally safe, and (3) cost-effective.

10.3.2 Design Data

The following information is included as given design data and was useful in executing the subsequent design.

10.3.2.1 Treatment Plant Description

The proposed municipal wastewater treatment plant was to be a modern secondary treatment facility. Further information on the facility is as follows:

1. Service population equivalent = 50,000
2. Average flow = 5.0 Mgal/d (0.22 m^3/sec)
3. Industrial inflow = 0% of total inflow
4. Wastewater treatment processes:

    a. bar screen separation
    b. primary clarifier
    c. secondary clarifier
    d. sand filters
    e. chlorine contact tanks

10.3.2.2 Sludge Description

Sludge was to be generated primarily from two sources (primary and secondary clarifiers). The sludge was to be anaerobically digested and dewatered. A more complete description is as follows:

1. Sludge sources:

   a. primary clarifiers
   b. secondary clarifiers

2. Sludge treatment:

   a. gravity thickening
   b. mixing
   c. anaerobic digestion
   d. dewatering via belt presses

3. Sludge characteristics (based on treatment plant design report)

   a. solids content = 29%
   b. quantity on a dry weight basis = 3.25 dry tons/day (2.95 Mg/day)

   c. quantity on a wet weight basis = 11.2 wet tons/day (10.2 Mg/day)

   d. density = 1,750 lbs/yd^3 (1,039 kg/m^3)

   e. quantity on a wet volume basis

$$\frac{(11.2 \text{ tons/day}) \times (2{,}000 \text{ lbs/ton})}{(1{,}700 \text{ lbs/yd}^3)}$$

$$= 13.2 \text{ yd}^3\text{/day } (10.1 \text{ m}^3\text{/day})$$

10.3.2.3 Climate

Significant climatological factors having an impact on sludge landfilling are listed below:

1. Precipitation = 48 in./yr (122 cm/yr)
2. Evaporation = 30 in./yr (76 cm/yr)
3. Number of days minimum temperature 32°F (0°C) and below = 125 days/yr

As shown, the climate is quite cold with freezing temperatures prevailing much of the year. Precipitation is high and evaporation exceeds precipitation by 18 in./yr (46 cm/yr).

10.3.2.4 General Site Description

Site data was collected from existing information sources as well as field investigations performed during the site selection process. This data is summarized below:

1. Size of property = 12 acres
2. Property line frontage:
   a. 1,750 ft (533 m) along woodland
   b. 500 ft (152 m) along crop land
   c. 850 ft (259 m) along a county road with woodland on the other side
3. Slopes = relatively flat with slopes at approximately 2%
4. Vegetation:
   a. 6.5 acres (2.6 ha) of woodland
   b. 5.5 acres (2.2 ha) of open space sparsely covered with grasses
5. Surface water = none on site; drainage on site via overland sheet flow into roadside ditch

A plan view of the site is presented in Figure 10-4. As shown, the site has good access from a two-lane county road adjoining the property. Approximately, one-half of the site is wooded; the balance is open space with some grasses. Cropland adjoins the property to the east. Other adjoining properties are undeveloped and wooded.

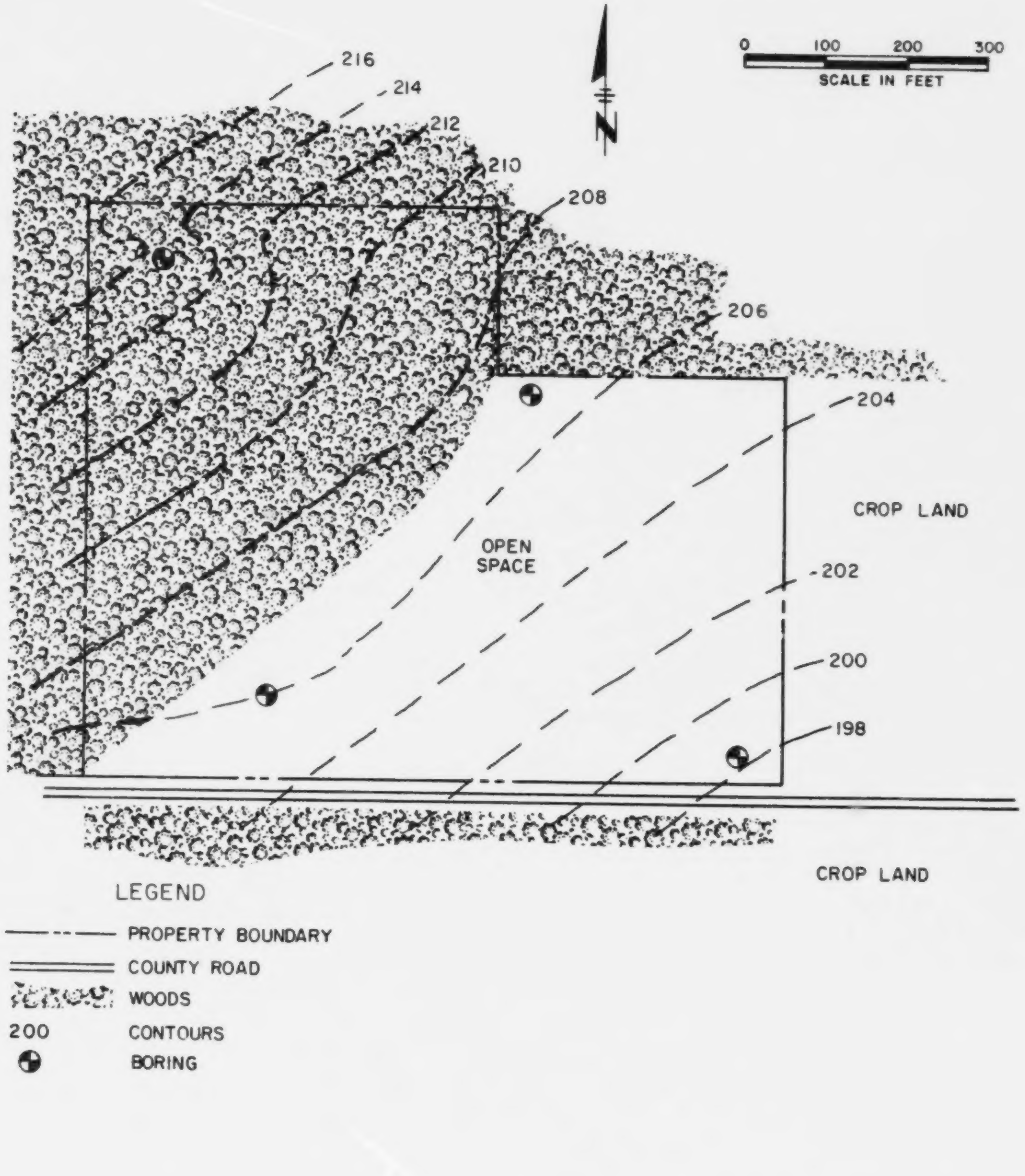
10.3.2.5 Hydrogeology

During the site selection phase, soil maps for the area were reviewed. In addition, logs of soil borings and wells drilled near the site were examined. Historical records compiled on nearby drinking water wells were reviewed for groundwater levels and seasonal fluctuations.

Subsequent to the site selection, four soil borings were performed at the site to verify subsurface conditions. These borings are located as shown in Figure 10-4. Subsurface conditions were found to be somewhat consistent at all boring locations and can be summarized as follows:

FIGURE 10-4

SITE BASE MAP FOR EXAMPLE NO. 2



Depth	Description
0-10 ft (0-3.0 m)	Coarse sand with silty sand
>10 ft (>3.0 m)	Saturated coarse sand

As shown above, the soil was primarily a coarse sand; however, the sand had some layers of silty sand interspersed throughout. Groundwater was at a 10 ft (3.0 m) depth. Due to the site's location on the coastal plain, bedrock is deep. Samples of the coarse sand were collected for analysis and the following determinations were made.

1. Texture = coarse
2. Permeability = 8 x 10^{-4} cm/sec
3. Permeability class = moderately rapid
4. pH = 6.0
5. Cation exchange capacity (CEC) = 8 meq/100 g

10.3.3 Design

10.3.3.1 Landfilling Method

Table 3-7 in Chapter 3 (Sludge Characteristics and Landfilling Methods) should be consulted as a reference. Since the sludge is stabilized and has a solids content of 29%, this sludge can be disposed in any of the five sludge-only methods shown. Also, none of these five methods are disqualified on the basis of slopes, since the site is relatively flat (2% slopes).

Because the site was relatively small and a longer site life was desired, it was obvious early in the design process that a high sludge application rate was required. As shown in Table 3-8, the highest sludge application rates are attained with wide trenches, area fill mounds, and diked containments. Diked containment was ruled out because the high application rates sometimes achieved with this method are only possible for large diked containments (with high dikes) receiving large quantities of sludge. Wide trenches were intially selected based on the cost- effectiveness of this operation versus area fill mounds. However, subsurface application of sludge at this site was marginal. Normally, a 10 ft (3.0 m) depth to groundwater would be sufficient to allow excavation and still provide sufficient buffer soils. However, the soil's coarse texture, moderately rapid permeability, low pH, and low CEC all indicated a strong potential for contaminant movement with insufficient attenuation. Although minimum soil bufgfers of 2 to 5 ft (0.6 to 1.5 m) are adequate in many cases, the State mandated an 8 ft (2.4 m) soil buffer between sludge deposits and groundwater. Therefore, it became apparent that surface landfilling of sludge in area fill mounds might be the only alternative.

However, area fill mounds have disadvantages in high precipitation areas such as at this site. Therefore, subsurface placement of sludge in lined wide trenches was introduced into consideration.

10.3.3.2 Design Dimensions

Preliminary designs were performed for each of the landfilling methods still under consideration. The purpose of these designs was to provide a basis for the site life and cost for each method. Subsequently, a selection of the method could be made using the life and cost of each. Using Tables 5-5 and 5-7 in Chapter 5 (Design), design dimensions were computed for each method as shown in Table 10-3.

TABLE 10-3

DESIGN CONSIDERATIONS FOR EXAMPLE NO. 2

Design Consideration	Wide Trench	Area Fill Mound
Width	50 ft	--
Depth	8 ft	--
Length	200 ft	--
Spacing	20 ft	--
Bulking performed	no	yes
Bulking agent	--	soil
Bulking ratio	--	1 soil: 1 sludge
Sludge depth per lift	4 ft	6 ft
No. of lifts	1	1
Cover applied	yes	yes
Location of equipment	sludge-based	sludge-based
Interim cover thickness	--	--
Final cover thickness	4 ft	3 ft
Imported soil required	no	yes

1 ft = 0.305 m

10.3.3.3 Site Development

Site development was planned in accordance with Figures 10-5 and 10-6 for wide trench and area fill mound operations, respectively. Features included in both plans are as follows:

1. A buffer was maintained to all adjoining property. Where wooded areas existed along property frontages, a 100 ft (30 m) wide strip was maintained in its natural state. Where grassy open space areas existed along property frontages, a 150 ft (46 m) wide strip was undisturbed.
2. A sodded diversion ditch was included along the uphill side of the site to intercept upland drainage. Intercepted runoff was directed to existing roadside ditches.

FIGURE 10-5

SITE DEVELOPMENT PLAN FOR EXAMPLE NO. 2 WIDE TRENCH

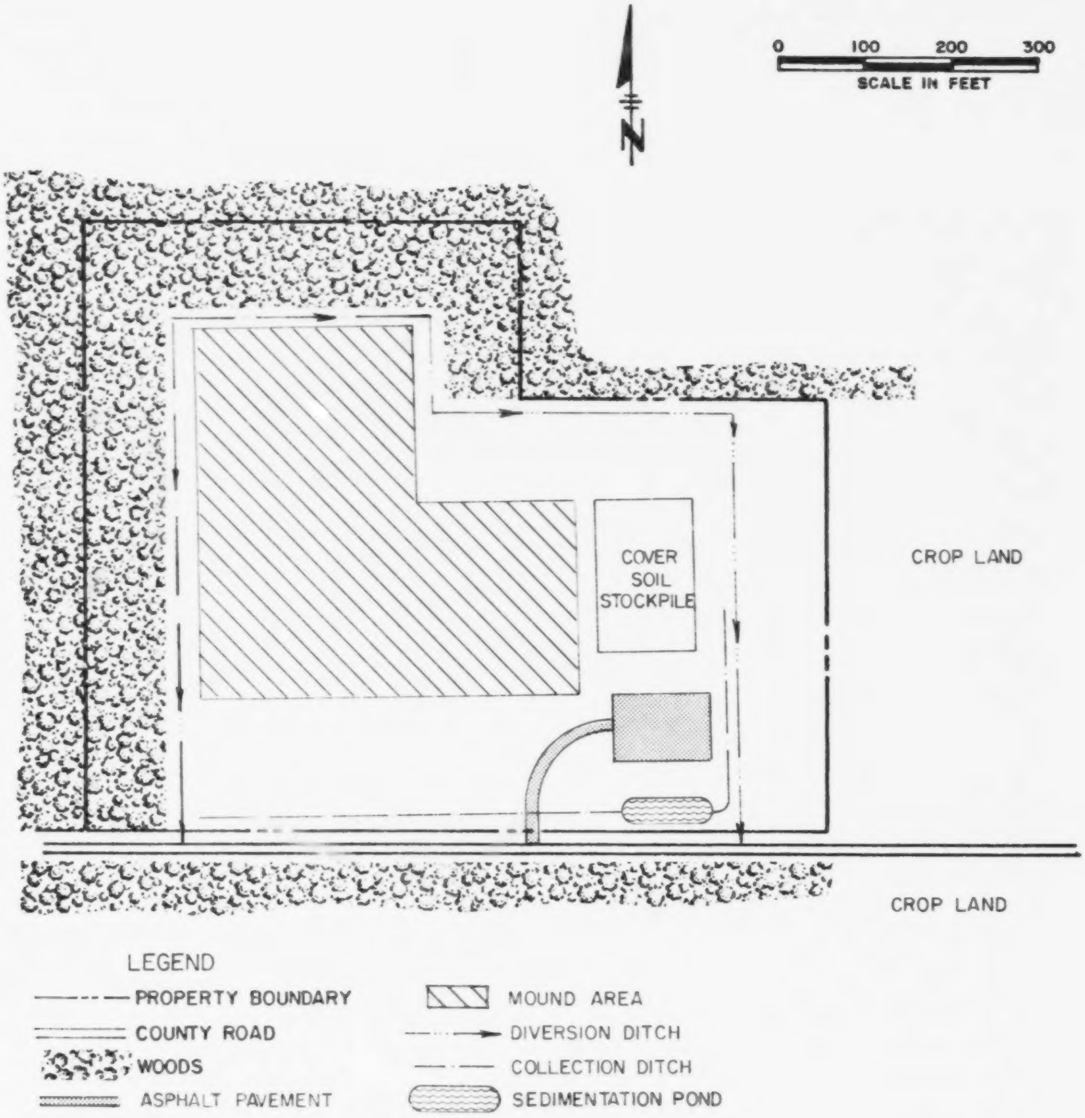
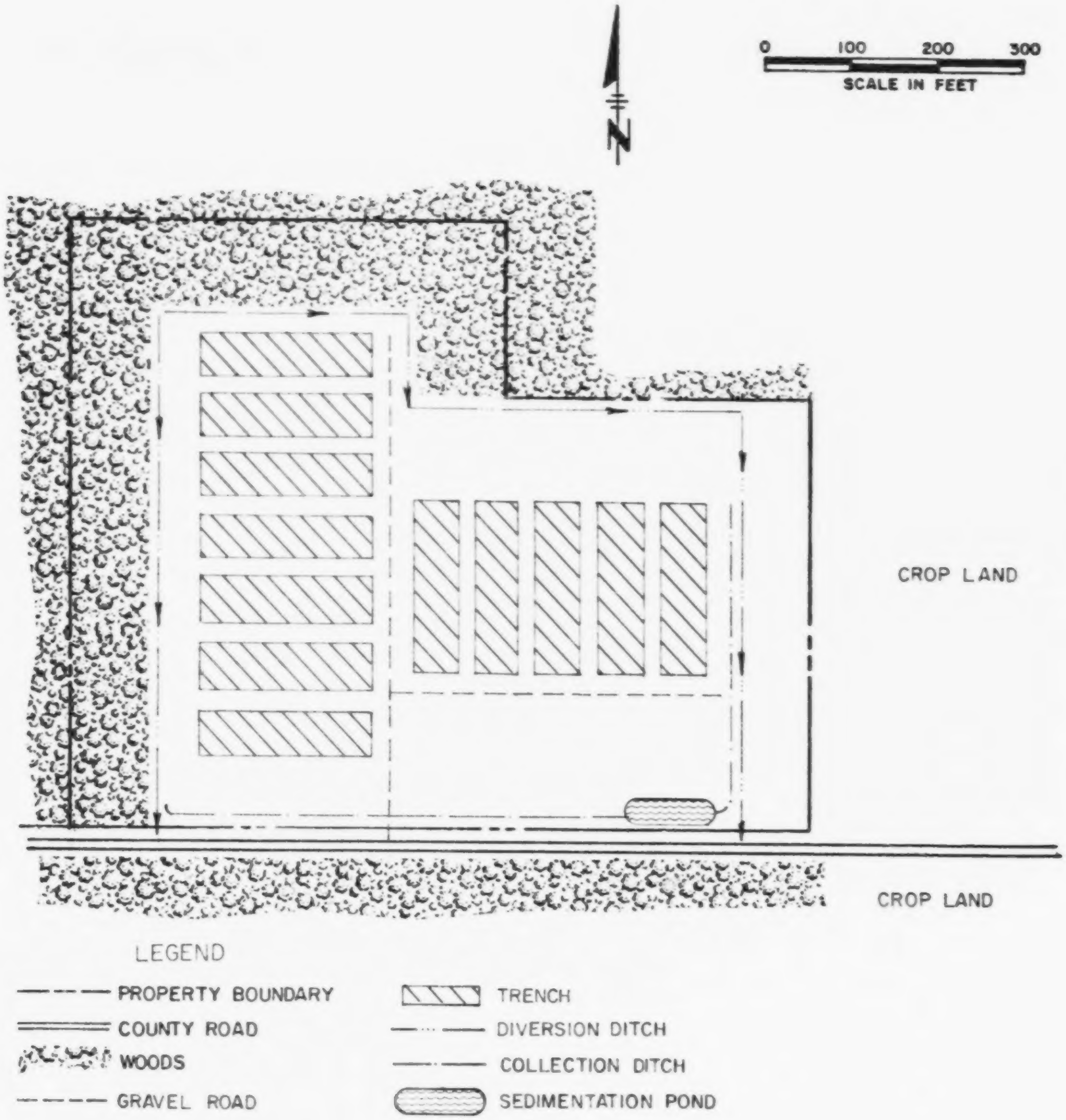


FIGURE 10-6

SITE DEVELOPMENT PLAN FOR EXAMPLE NO. 2 AREA FILL MOUND



3. A sodded collection ditch was included along the downhill side of the site to intercept on-site drainage. Intercepted runoff was directed to a new sedimentation pond.

Features specific to the wide trench operation shown in Figure 10-4 included the following:

1. Trenches were laid out in accordance with design dimensions and made optimal use of available land.
2. Gravel roads were constructed as shown to provide access from the site entrance to individual trenches.
3. Sheets of 20 mil (0.05 cm) Hypalon were selected for application to the floor and sidewalls (2:1 slope) of all trenches.

Features specific to the area fill mound operation shown in Figure 10-5 included the following:

1. An asphalt-paved dumping/mixing pad and access road were specified.
2. A soil stockpile area was located near the dumping/mixing pad. Soil for this stockpile was imported once each year from another location incurring a 3-mile haul.
3. Most of the remaining site area was designated for sludge mounding operations.

10.3.3.4 Calculations

Based on the design data and dimensions stated previously, calculations were performed for each of the proposed landfilling methods. Determinations made on the wide trench application include:

1. Trench capacity = 1,481 yd^3/trench (1,132 m^3/trench)
2. Number of trenches = 12
3. Site capacity = 17,772 yd^3 (13,588 m^3)
4. Sludge volume received = 13.2 yd^3/day (10.1 m^3/day)
5. Site life = 3.7 years

Determinations made on the area fill mound application include:

1. Sludge application rate = 9,680 yd^3/acre (18,295 m^3/ha)
2. Size of mounding area = 3 acres (1.22 ha)
3. Site capacity = 29,040 yd^3 (22,204 m^3)
4. Sludge volume received = 13.2 yd^3/day (10.1 m^3/day)
5. Site life = 6.0 years

10.3.3.5 Equipment and Personnel

Using Table 6-4 in Chapter 6 (Operation) as a reference, the following equipment and personnel were selected for use at the wide trench operation:

Description	Quantity	Hours per Week
Track dozer	1	10
Track dozer operator	1	15

The following equipment and personnel were selected for use at the area fill mound operation:

Description	Quantity	Hours per Week
Track loader	1	15
Track loader operator	1	20

10.3.3.6 Cost Estimates

Cost estimates were computed for each of the proposed landfilling methods. These estimates have been included as Tables 10-4 through 10-7. As shown, the annual operating cost of the wide trench operations was calculated at $30,195. The total capital cost was calculated at $95,552. This amount was amortized at 7% interest over 4 years (the approximate life of the wide trench operation). The amortized capital cost derived was $28,209.

The annual operating cost of the area fill mound operation was calculated at $44,624. The total capital cost was calculated at $107,325. This amount was amortized over 6 years (the life of the area fill mound operation). The amortized capital cost derived was $22,517.

TABLE 10-4

ESTIMATE OF TOTAL SITE CAPITAL COSTS FOR EXAMPLE NO. 2 WIDE TRENCH

Item	Quantity	Unit Cost	Total Cost
Land	12 acres	$ 2,500/acre	$30,000
Site Preparation			
Clearing and Grubbing	6 acres	$ 705/acre	$ 4,230
Sodded Division Ditch	1,750 ft	$ 2.50/ft	$ 4,375
Sodded Collection Ditch	850 acres	$ 2.50/ft	$ 2,125
Pond	1 ea	$ 3,000/ea	$ 3,000
Monitoring Wells	3 ea	$ 300/ea	$ 900
Gravel Roads	950 ft	$ 1.85/ft	$ 1,757
Miscellaneous	--	--	$ 2,000
Equipment			
Track Dozer	1 ea	$41,760/ea	$41,760
Subtotal	--	--	$90,147
Engineering @ 6%	--	--	$ 5,405
Total	--	--	$95,552

1 acre = 0.405 ha
1 ft = 0.305 m

TABLE 10-5

ESTIMATE OF ANNUAL SITE OPERATING COSTS FOR EXAMPLE NO. 2 WIDE TRENCH

Item	Quantity	Unit Cost	Total Cost
Labor			
Dozer Operator	780 hrs	$8.00/hr	$ 6,240
Equipment Fuel, Maintenance and Parts			
Track Dozer	520 hrs	$4.50/hr	$ 2,340
Hypalon Liner (installed)	2,700 ft^2	$0.45/$ft^2$	$ 1,215
Laboratory Analysis	--	--	$ 2,500
Other Supplies and Materials	--	--	$ 5,000
Miscellaneous	--	--	$ 2,000
Total	--	--	$30,195

1 ft^2 = 0.093 m^2

TABLE 10-6

ESTIMATE OF TOTAL SITE CAPITAL COSTS FOR EXAMPLE NO. 2 AREA FILL MOUND

Item	Quantity	Unit Cost	Total Cost
Land	12 acres	\$ 2,500/acre	\$ 30,000
Site Preparation			
Clearing and Grubbing	6 acres	\$ 705/acre	\$ 4,230
Sodded Division Ditch	1,750 ft	\$ 2.50/ft	\$ 4,375
Sodded Collection Ditch	850 ft	\$ 2.50/ft	\$ 2,125
Pond	1 ea	\$ 3,000/ea	\$ 3,000
Monitoring Wells	3 ea	\$ 300/ea	\$ 900
Asphalt Paving	4,200 ft^2	\$ 0.45/ft^2	\$ 1,890
Miscellaneous	--	--	\$ 2,000
Equipment			
Track Loader	1 ea	\$52,730/ea	\$ 52,730
Subtotal	--	--	\$101,250
Engineering @ 6%	--	--	\$ 6,075
Total	--	--	\$107,325

1 acre = 0.405 ha
1 ft = 0.305 m
1 ft^2 = 0.093 m^2

TABLE 10-7

ESTIMATE OF ANNUAL SITE OPERATING COSTS FOR EXAMPLE NO. 2 AREA FILL MOUND

Item	Quantity	Unit Cost	Total Cost
Labor			
Loader Operators	1,040 hrs	\$ 8.00/hr	\$ 8,320
Equipment Fuel, Maintenance, and Parts			
Track Loader	780 hrs	\$ 8.98/hr	\$ 7,004
Laboratory Analysis	--	--	\$ 2,500
Supplies and Materials	--	--	\$ 5,000
Miscellaneous	--	--	\$ 2,000
Total	--	--	\$24,824

Unit costs for each operation were compiled and are summarized below:

	Amortized Capital Cost	Operating Cost	Total Cost
Wide trench	$6.90/wet ton ($7.61/Mg)	$7.39/wet ton ($8.15/Mg)	$14.29/wet ton ($15.76/Mg)
Area fill mound	$5.51/wet ton ($6.07/Mg)	$9.26/wet ton ($10.21/Mg)	$14.77/wet ton ($16.28/Mg)

10.3.3.7 Conclusion

An area fill mound operation was subsequently selected and utilized. Although the mound operation actually cost more than the wide trench, the cost difference was not that substantial and the mounding operations longer life made it the clear-cut choice.

10.4 Design Example No. 3

10.4.1 Statement of Problem

The problem was to design a sludge-only landfill on the site of a wastewater treatment plant serving a population equivalent of 5,000. The plant had been disposing of their 34% solids sludge at a refuse landfill 8 miles (13 km) distant. However, landfill operators were now charging $8.00 per wet ton ($8.82 per Mg) for the sludge; treatment plant operators sought the cost-savings that might be realized by landfilling the sludge themselves. The recommended design had to be (1) in compliance with pertinent regulations, (2) environmentally safe, and (3) cost-effective.

10.4.2 Design Data

The following information is included as given design data and was useful in executing the subsequent design.

10.4.2.1 Treatment Plant Description

Ther existing wastewater treatment facility was a package plant. Further information on the facility is as follows:

1. Service population equivalent = 5,000
2. Average flow = 0.5 Mgal/d (0.022 m^3/sec)
3. Industrial inflow = 0% of total inflow
4. Wastewater treatment processes:
   a. bar screen separation
   b. primary clarifier
   c. aeration tanks
   d. secondary clarifier

10.4.2.2 Sludge Description

Sludge from the secondary clarifier was recirculated to the primary clarifier. The sludge was stabilized and dewatered. A more complete description is as follows:

1. Sludge sources - sludge from secondary clarifier recirculated to primary clarifier and withdrawn as mixture with primary sludge

2. Sludge treatment:
   a. aerobic digestion
   b. dewatering via sand drying beds

3. Sludge characteristics (based on testing, review of records, and calculations)
   a. solids content = 34%
   b. quantity on a dry weight basis = 0.33 dry tons/day (0.30 Mg/day)
   c. quantity on a wet weight basis = 0.96 wet tons/day (0.87 Mg/day)
   d. density = 1,850 lbs/yd^3 (1,098 kg/m^3)
   e. quantity on a wet volume basis = 1.03 yd^3/day (0.79 m^3/day)

10.4.2.3 Climate

Significant climatological factors having an impact on sludge landfilling are listed below:

1. Precipitation = 32 in./yr (81.3 cm/yr)
2. Evaporation = 34 in./yr (86.4 cm/yr)
3. Number of days minimum temperature 32°F (0°C) and below = 40 days/yr

As shown the climate is marked by mild temperatures. Precipitation and moderate and is exceeded slightly by evaporation.

10.4.2.4 General Site Description

The area to be used for sludge landfilling occupied a 3-acre (1.2 ha) portion of the 8-acre (3.2 ha) treatment plant property. It was located immediately adjacent to the plant's sand drying beds. Other data concerning this 3-acre tract is summarized below:

1. Adjoining properties and facilities:
   a. 700 ft (210 m) abuts woodland which is privately owned
   b. 700 ft (210 m) abuts treatment plant facilities
2. Slopes = evenly sloped at about 6%
3. Vegetation = all 3 acres (1.2 ha) had been previously cleared and are covered with grasses
4. Surface water = none of the 3-acre (1.2 ha) tract. A stream which receives effluent from the treatment is located 500 ft (150 m) away.

10.4.2.5 Hydrogeology

Site hydrogeological data was collected largely from information contained in the treatment plant report and drawings. Some additional information on soils, bedrock, and groundwater was obtained from the sources listed in Table 5-3 of Chapter 5 (Design).

Subsurface conditions are summarized as follows:

Depth	Description
0-10 ft (0.3.0 m)	Silty clay with some clay lenses interspersed throughout
10-12 ft (3.0-3.7 m)	Saturated silty clay
12-15 ft (3.7-4.6 m)	Clay
15-26 ft (4.6-7.9 m)	Saturated silty clay
>26 ft (7.9 m)	Bedrock

As shown, the upper 10 ft (3.0 m) of soil was a dry silty clay; groundwater was encountered at a 10 ft (3.0 m) depth. A 3 ft (0.9 m) thick tight clay seam protects the groundwater located below it. Using Tables 4-1 and 4-2 and Figure 4-4 and 4-5 from Chapter 4 (Site Selection), the following determinations were made:

1. Texture = fine
2. Permeability = approximately 10^{-7} cm/sec
3. Permeability class = very slow
4. Cation exchange capacity (CEC) = over 20 meq/100 g

10.4.3 Design

10.4.3.1 Landfilling Method

Table 3-7 should be consulted as a reference. This site was conducive to subsurface placement of sludge since (1) groundwater and bedrock are relatively deep (at 10 and 26 ft (3.0 and 7.9 m), respectively) and (2) the soils are tight enough to afford sufficient environmental protection even when sludge is placed relatively close to the groundwater. Since area fills are generally more manpower and equipment-intensive then trenches, trenches should be selected in almost all instances where hydrogeologic conditions allow. In addition, wide trenches should be selected over narrow trenches for sludge with a solids content of 34% as shown in Table 3-8. Cover application should be via sludge-based equipment. All of these considerations were established and utilized in the preliminary design.

10.4.3.2 Design Dimensions

Using Table 5-5, the following design dimensions were established:

1. Width = 20 ft (6.1 m)
2. Depth = 8 ft (2.4 m)
3. Length = 100 ft (30 m)
4. Spacing = 30 ft (9.1 m)
5. Sludge fill depth = 5 ft (1.5 m)
6. Cover thickness = 4 ft (1.2 m)

Test trenches were then constructed on the site and operated under proposed conditions to ensure their effectiveness and practicality in a full-scale operation. The test was successful and the design proceeded based on the above dimensions.

10.4.3.3 Calculations

Based on the design data and dimensions stated previously, calculations were performed for each of the proposed landfilling methods. Determinations made on the operation included:

1. Trench capacity = 375 yd^3 (287 m^3)
2. Number of trenches = 20
3. Site capacity = 7,500 yd^3 (5,734 m^3)
4. Sludge volume received = 1.03 yd^3/day (0.79 m^3/day)
5. Site life = 20 years

10.4.3.4 Operational Procedures

Site preparation, on-going operations, and site completion consist of the following procedures:

1. Twice each year a contractor is employed to excavate sufficient trench capacity for a 6 month sludge quantity. The contractor uses a single front-end loader to excavate each 20 ft (6.1 m) wide trench to a depth of 8 ft (2.4 m). Excavated soil is stockpiled above and along both sides of the trench.

2. Immediately after the trench is excavated, 6 months accumulation of sludge is removed from sand drying beds with pitchforks and loaded on a dump truck owned by the treatment plant.

3. The sludge is hauled the short distance to the trenching area. At that location, dump trucks back into the trenches from the open end of the trench and deposit the sludge in 3 to 4 ft (0.9 to 1.2 m) high piles.

4. A bulldozer enters the trench intermittently to push the sludge into a 5 ft (1.5 m) high accumulation.

5. After each trench is filled to completion, the bulldozer is employed to spread cover over the 20 ft (6.1 m) wide trench from the soil stockpiles located on either side. The cover is spread in a 4 ft (1.2 m) thick application to 1 ft (0.3 m) above grade.

6. The completed trench is then seeded to promote the growth of grasses.

7. Usually settlement of the trenches is not too severe due to the high solids content of the sludge and the cover thickness. However, once each year the bulldozer employed for landfilling operations is used to regrade completed trenches from the previous year. These trenches are then reseeded.

10.4.3.5 Cost Estimates

The cost estimate prepared for this operation is presented in Table 10-8. As shown, the total cost was computed at $1,109 per year. Considering a sludge quantity of 379 wet tons per year (344 Mg per year), this equates to $2.93 per wet ton ($3.23 per Mg). This represents a savings of $5.07 per wet ton ($5.59 per Mg) when compared to the fee being charged by the local landfill. Accordingly, plant operators initiated the previously described operation.

TABLE 10-8

ESTIMATE OF TOTAL ANNUAL COST FOR EXAMPLE NO. 3

Item	Quantity	Unit Cost	Total Cost
Mobilization			
Loader	2 ea	$50/ea	$ 100
Dozer	2 ea	$50/ea	$ 100
Trench Excavation	600 yd^3	$\$0.90/yd^3$	$ 540
Covering	230 yd^2	$\$0.60/yd^2$	$ 138
Regrading	230 yd^2	$\$0.30/yd^2$	$ 69
Seeding	450 yd^2	$\$0.36/yd^2$	$ 162
Total			$ 1,109

1 $yd^3 = 0.765\ m^3$
1 $yd^2 = 0.836\ m^2$

It should be noted that costs as low as $2.93 per wet ton ($3.23 per Mg) cannot be achieved by most treatment plants of this size. One of the reasons the cost was low was that this plant was able to landfill 6 months sludge in one or two days. Under these circumstances, this facility was able to achieve economies-of-scale usually found only at very large sludge landfills.

CHAPTER 11

CASE STUDIES

11.1 Introduction

Five case studies are presented in this chapter to illustrate the variety of existing landfilling methods. Of the five, one is a narrow trench operation, two are wide trench operations, one is an area fill layer operation, and one is a codisposal operation. The five case studies included in the manual were selected from a total of 22 sludge landfills that were studied in detail.

11.2 Case Study Summaries

The twenty-two sludge landfills were studied to identify site selection, design, and operation procedures that are relevant to sludge landfilling. In addition, public participation, monitoring, costs, equipment, and personnel for each site were examined. The data was accumulated via site visits and interviews with site operators, planners, and designers.

A summary of the above-described information has been compiled on the next four pages. Figure 11-1 shows the locations of the sites and Table 11-1 summarizes the treatment processes and resulting sludge quantities for each site. Design and operational features are presented in Table 11-2. Hauling and site costs are detailed in Table 11-3. The data contained in these compilations was useful in observing trends and establishing design criteria. As a result, this data formed the basis for much of the information presented in this manual. The reader may find it equally useful to peruse this data in determining trends and criteria relevant to a specific operation.

FIGURE 11-1

LOCATION OF CASE STUDY SITES

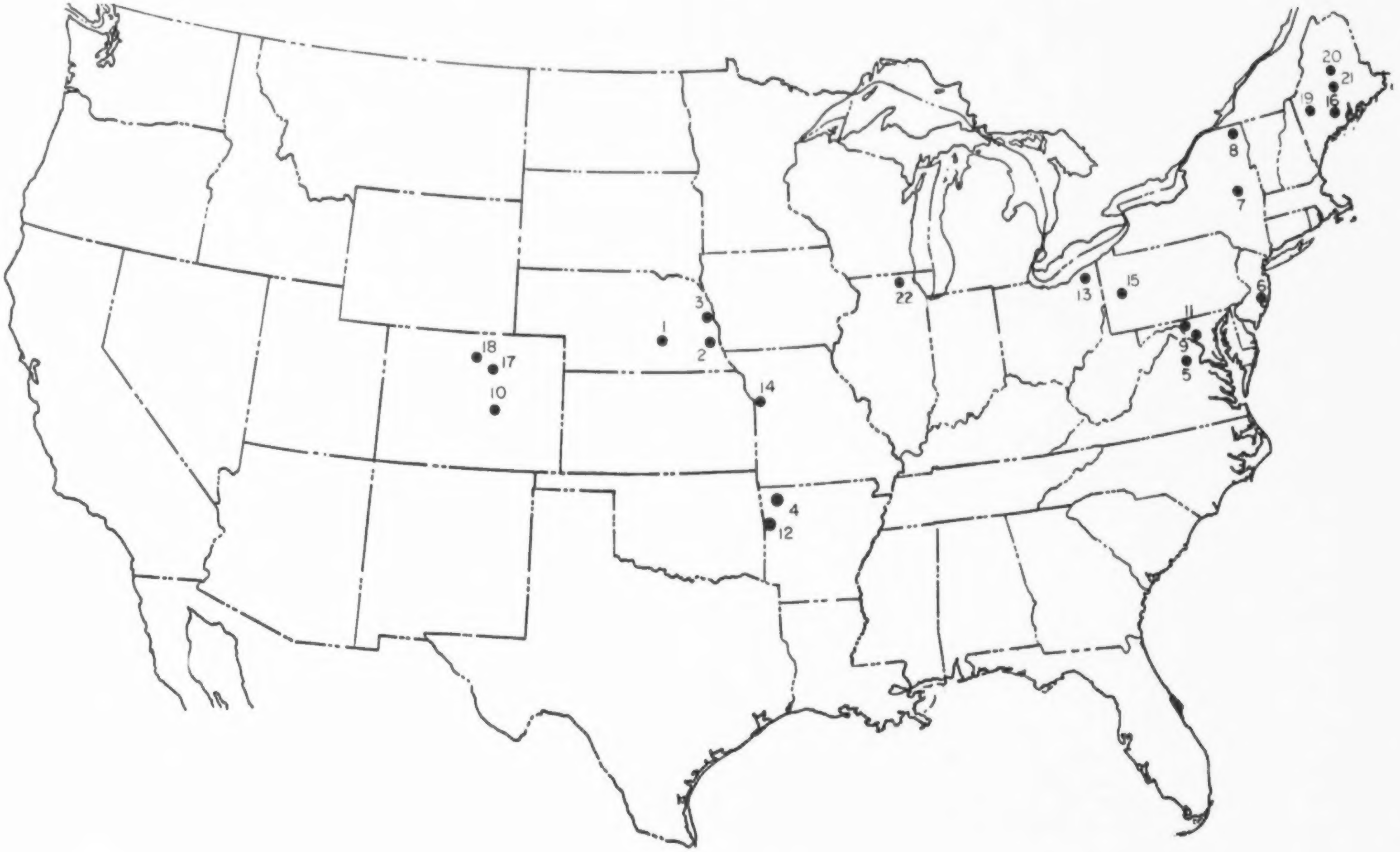


TABLE 11-1

SITE IDENTIFICATION AND SLUDGE DESCRIPTION

SITE IDENTIFICATION		SLUDGE RECEIVED								
				Quantity per Day			Quantity per Year			Sludge as % of total waste (if codisposal)
No.	City/County, State	Treatment Processes	Ave. % Solids	Yd^3	Wet tons	Dry tons	Yd^3	Wet tons	Dry tons	
1	Grand Island, NE	CA,DE	28	39	35	10	9,900	9,000	2,500	15
2	Lincoln, NE	DE	22	9	8	2	3,100	2,800	630	11
3	Omaha, NE	CA,DE	28	237	215	56	67,700	61,500	16,000	--
4	Fayetteville, AK	CA,DE	20	17	15	3	5,960	5,300	1,060	--
5	Lorton, VA	CA,DI,DE	22	213	190	42	66,000	59,000	13,000	11
6	Stafford, NJ	DI	4	12	10	0.4	3,000	2,540	100	5
7	Johnstown, NY	DE	37	23	21	8	6,000	5,600	2,100	31
8	Plattsburgh, NY	DE	12	161	140	18	58,600	51,000	6,400	--
9	Montgomery County, MD	CA,DE	22	450	400	87	119,200	106,000	23,000	--
10A	Colorado Springs, CO TR(W)	CA,DE	22	61	55	12	22,000	20,000	4,400	--
10B	Colorado Springs, CO TR(N)	DI	3	543	470	14	141,000	122,000	3,650	--
11	Frederick, MD	DE	30	33	30	9	7,660	7,000	2,100	--
12	Fort Smith, AK	DE	30	30	27	8	6,240	5,700	1,710	--
13	Cleveland, OH	CA,DI,DE	26	502	450	99	183,000	164,000	36,000	--
14	N. Kansas City, MO	CA,DE	32	11	10	3	1,700	1,560	500	--
15	Pittsburgh, PA	DE	22	112	100	22	33,500	30,000	6,750	12
16	Lewiston-Auburn, ME	CA,DE	21	65	57	12	17,100	15,000	3,100	--
17	Denver, CO	CA,DI,DE	15	833	666	100	250,000	220,000	33,400	--
18	Boulder, CO	CA,DI,DE	20	56	50	10	14,000	12,500	2,600	14
19	South Paris, ME	DE	14	83	64	9	25,900	20,000	2,800	--
20	Hartland, ME	CA,DE	19	66	58	11	17,200	15,100	2,900	--
21	Waterville, ME	CA,DE	20	49	43	9	18,000	15,800	3,300	--
22	Waukegan, IL	CA,DE	22	200	177	39	52,400	46,400	10,200	--

Legend: CA - Chemical Addition
DI - Digestion
DE - Dewatering
TR(N) - Trench Narrow
TR(W) - Trench Wide

1 ton = 0.907 Mg
yd^3 = 0.7647 m^3

TABLE 11-2

SITE DESIGN AND OPERATION

Site no.	EXISTING CONDITIONS					Operational method	SITE PREPARATION					SITE OPERATION									ON-SITE EQUIPMENT										On-site labor (M-H per week)
	Soil type	Original depth to groundwater (ft)	Freezing days/yr	Precipitation (in./yr)	Evaporation (in./yr)		Trench width (ft)	Trench depth (ft)	Trench length (ft)	Trench spacing (ft)	Sludge to groundwater (ft)	Sludge application (yd^3 per acre)	Fill depth (ft)	Sludge application (ft^2 per acre)	Soil used for bulking	Bulking ratio (sludge:soil)	Soil used for cover	Cover thickness (ft)	Sludge exposure (days)	Total soil usage (waste:soil)	Track-type loader	Rubber-tired loader	Bulldozer	Backhoe	Dragline	Scraper	Trencher	Grader	Other	Total	
1	Sand and Gravel	10-20	145	22	70	CD(R)	—	—	—	—	5-15	—	—	—			X	0.5-2	< 1	1:0.33	2	—	—	—	—	—	—	—	—	2	120
2	Silt and Clay	10	135	27	62	CD(R)	—	—	—	—	0-1	—	—	—			X	0.5-2	< 1	1:0.33	—	—	3	—	1	—	—	—	—	4	160
3	Sandy Silt and Clay	22	140	28	58	TR(W)	15	20	30	10	8	14,500	20	19,600			X	2	30	1:0.11	1	—	—	—	1	—	—	1	—	3	40
4	Silty Clay	10	90	52	59	TR(N)	2-3	10	*	7-10	2	2,900	9.5	8,200			X	2	3-4	1:0.2	—	—	—	1	—	—	—	—	—	1	80
5	Sand, Silt, and Clay	0-40	85	41	47	CD(R)	—	—	—	—	2	—	—	—			X	0.5-2	< 1	1:0.33	—	2	5	—	—	3	—	1	6	17	1,500
6	Sand	5-25	70	44	42	CD(R)	—	—	—	—	10	—	—	—			X	0.5-2	< 1	1:0.33	—	1	1	—	—	—	—	—	—	2	120
7	Loamy Sand	20	140	42	36	CD(S)	—	—	—	—	20-40	—	—	—	X	1:1			30	1:0.5	—	1	1	—	—	—	—	—	1	3	80
8	Sand, Silt, and Clay	2-15	170	36	32	TR(W)	350	20	1,100	50	2	24,300	18	36,500						1:0.25	1	2	4	—	—	—	—	—	—	7	180
9	Silty Loam	6-36	90	40	47	TR(N)	2	3	*	2	3	1,275	2	17,200			X	3	< 1	1:1	2	—	—	—	—	—	2	—	9	13	480
10A	Silt and Clay	> 10	120	13	60	TR(W)	70	7	700	20-25	> 5	4,700	4	31,800			X	4	< 1	1:1	—	—	2	—	—	1	—	—	—	3	50
10B	Silt and Clay	> 10	120	13	60	TR(N)	2	10	150	15-20	2-3	1,150	7	4,400			X	5	4	1:08	—	—	2	1	—	—	1	—	—	4	90
11	Clay	36	105	41	45	AF(L)	—	—	—	—	16	7,300	18	11,000	X	1:1.5	X	2-3	< 1	1:2	—	1	—	—	—	1	—	—	—	2	80
12	Silty Loam	8-10	75	44	64	TR(N)	2.5	8	*	4-6	2	2,500	5	13,500			X	6.5	< 1	1:1.3	—	—	1	1	—	—	—	1	—	3	40
13	Sand, Silt, and Clay	10-40	120	34	40	TR(W)	40	5-6	450	5-10	4-34	3,800	3	34,200			X	3-6	< 1	1:1.3	—	—	2	—	2	1	—	1	—	6	180
14	Clay, Silt, and Sand	12	105	35	59	TR(W)	12	10	100	4-5	2	10,600	13	22,000			X	7	21	1:1	—	—	1	1	1	—	—	—	—	3	40
15	Sand	> 50	120	38	39	CD(R)	—	—	—	—	50	—	—	—			X	0.5-2	< 1	1:0.33	—	—	2	—	—	2	—	3	1	8	280
16	Sand, Gravel, and Clay	0-1	160	44	31	AF(M)	—	—	—	—	0-1	14,000	15	25,200	X	1:1			4	1:1	—	—	1	1	—	—	—	—	—	2	40
17	Clay, Sand and Gravel	10-140	240	14	60	AF(L)	—	—	—	—	10-140	9,000	17.5	13,900	X	1:1.5			< 1	1:5	—	1	2	—	—	1	—	1	—	5	320
18	Sand and Gravel	> 10	240	16	50	CD(R)	—	—	—	—	> 10	—	—	—			X	0.5-2	< 1	1:0.33	—	—	1	—	—	1	—	1	—	3	120
19	Sand	45-70	160	44	31	TR(N)	6	6-8	40	4-10	37-62	4,500	5-7	20,000			X	3	< 1	1:0.5	—	—	—	1	—	—	—	—	—	1	80
20	Gravel and Clay	20	160	44	31	TR(W)	11-15	15	50	8	5	13,700	13	28,400			X	3	30	1:0.23	—	—	1	—	—	—	—	—	—	1	20
21	Gravel and Sand	40	160	44	31	AF(M)					40	8,600	12	19,400	X	1:0.6	X	1-2	60	1:0.85	—	1	—	1	—	—	—	—	—	2	80
22	Silty Clay	31-40	140	32	39	TR(W)	16-22	20	70	5,20	11-20	9,100	14	17,500			X	5	< 1	1:0.6	1	—	2	1	—	—	—	—	—	4	200

Legend:

— Not Applicable
* Variable

TR(N) - Narrow Trench
TR(W) - Wide Trench
AF(L) - Area Fill Layer

AF(M) - Area Fill Mound
CD(R) - Codisposal (Sludge/Refuse Mixture)
CD(S) - Codisposal (Sludge/Soil Mixture)

$yd^3/ac = 1.89\ m^3/ha$
1 ft = 0.305 m
1 in. = 2.54 cm
$ft^2/ac = 0.23\ m^2/ha$

TABLE 11-3

HAULING AND SITE COSTS

Site No.	Hauling Costs ($) Per yd^3	Hauling Costs ($) Per wet ton	Hauling Costs ($) Per dry ton	Site Costs ($) Per yd^3	Site Costs ($) Per wet ton	Site Costs ($) Per dry ton
1	--	--	--	0.50	0.55	1.96
2	--	--	--	0.91*	1.01*	4.59
3	--	--	--	2.35	2.59	9.25
4	--	--	--	3.03	3.41	17.05
5	--	--	--	4.45	4.98	22.64
6	--	--	--	2.12	2.50	62.50
7	--	--	--	4.16	4.46	12.05
8	1.57	1.80	14.40	1.05	1.21	10.08
9	15.92	17.90	83.25	28.14	31.64	143.82
10A	4.00	4.40	20.00	1.06	1.17	5.32
10B	1.42	1.64	54.67	0.57	0.66	22.00
11	--	--	--	1.96*	2.14*	7.13*
12	--	--	--	--	--	--
13	4.93	5.50	25.00	5.83	6.50	25.00
14	--	--	--	4.91	5.35	16.71
15	--	--	--	--	--	--
16	--	--	--	1.92	2.19	10.43
17	--	--	--	2.37*	2.69*	18.17*
18	--	--	--	1.64	1.84	9.20
19	0.17	0.22	1.57	1.03	1.33	9.50
20	--	--	--	1.03	1.17	6.15
21	--	--	--	--	--	--
22	--	--	--	2.93	3.31	10.61

* Operating costs only. Does not include site capital costs.

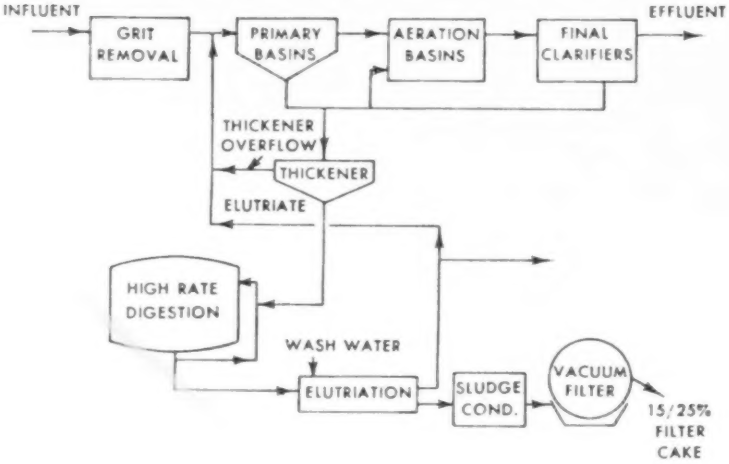
11.3 Montgomery County, Maryland

11.3.1 Background and History

Site 216 was located in Montgomery County, Maryland about 25 mi (40 km) east of Washington, DC. It received about half of the total sludge from the Blue Plains Treatment Plant which serves Washington DC. The plant uses a step aeration activated sludge process to treat a flow of 309 Mgal/d (13.5 m^3/s) with less than a 10% contribution from industrial sources (Figure 11-2). From this flow the site received about 106,000 wet tons (96,152 Mg) of primary and secondary sludge per year containing about 20 to 23% solids. The sludge is dewatered using gravity thickening and vacuum filtration. Lime is used in the treatment process to control pH, stabilize biological activity, and provide odor control. This contributed another 7,300 dry tons (6,621 Mg) of waste per year. An additional 2,700 dry tons (2,450 Mg) of ferric chloride and polymers from the treatment process was produced each year. The site opened in February of 1976 and closed in February 1978. Narrow trenches were selected as the landfilling method.

FIGURE 11-2

BLUE PLAINS TREATMENT PLANT FLOW DIAGRAM



11.3.2 Site Description

The site occupied 719 acres (290 ha) of gently sloping terrain. The highest elevations, 540 ft (165 m) mean sea level (MSL), were located in the eastern portion of the site and the lowest elevations, approximately

400 ft (122 m) MSL were found in the western portion. Site 216 was underlain by the Wissahickon Schist with a saprolite thickness varying between 20 to 50 or more ft (6 to 15 m) throughout the property. Other relevant site characteristics are detailed below.

- Topography - gently sloping; drains to Anacostia River
- Soil type - silty loam; moderately permeable
- Depth to groundwater - 6 to 36 ft (1.8 to 11 m)
- Groundwater use - aquifer provides potable water
- Freezing days - 90 days/yr
- Precipitation - 40 in./yr (102 cm/yr)
- Evaporation - 47 in./yr (119 cm/yr)

11.3.3 Site Selection

In general, the site selection process established physiographic, economic and other technical parameters inherent in a desirable disposal site and then identified suitable areas. The initial parameters included:

- Soils
- Topography
- Geology
- Surface and groundwater conditions

The first step in the selection process was to delineate suitable areas of the county based on these considerations. Acetate overlays indicating unsuitable areas were made for each of these criteria and placed over a county map. The areas remaining were characterized as "High Priority".

The County used this process to find areas that were generally suitable for sludge disposal. Some specific sites within the "High Priority" areas had poor drainage, inadequate soil cover, or other disqualifying characteristics; conversely, there were sites outside the area that met the geomorphic requirements of a sludge disposal site.

Using newspaper advertisements, real estate agents, past site inventories, and site visits the county identified 20 potential sites in these areas. These sites were in turn screened, and those that required elaborate modification such as tree cutting or extensive excavation were eliminated.

A total of 8 potential sites emerged from this process and were subjected to an in-depth screening based on the following criteria:

- Site physiography
  - expected life of the site
  - soils and geology
  - topography and slope
  - screening and buffer
  - groundwater
  - surface water

- Other technical considerations
  - zoning and land use
  - site availability
  - haul route

- Site costs
  - haul distance
  - site acquisition costs
  - site preparation costs

The current site (Site 216) was judged to be the best, based on the above criteria and on state and county policies outlined in Table 11-4. Figure 11-3 is a map of the site selected. It was purchased rather than leased, and realtors were notified of the purchase. In addition, several ads were placed in local newspapers so that the public was aware of the action.

TABLE 11-4

REGULATORY REQUIREMENTS RELATIVE TO SITE SELECTION AT MONTGOMERY COUNTY, MARYLAND

	Jurisdiction Code	Description of Constraint/Directive
1. Geology	SCS, MSH	Restrict site selection where shallow soil cover over bed rock, and where sand and gravel is present.
2. Soils	SCS, MSH	Set site selection criteria according to permeability, infiltration rate, runoff and susceptability to flooding.
3. Topography	MSH	Site selection - site in Patuxent watershed, classified as "secondary" or low priority.
	MES	12 percent maximum slope (operation limitation).
4. Groundwater	SCS, MSH	Buffer of 3 ft between the bottom of the trenches and the highest expected groundwater table level.
5. Surface Water	WRA	Eliminate sites that drain into Tridelphia and Rocky Gorge Water supply reservoirs. Buffer of 100 ft between streams and trenching operations.
6. Buffer and Screening	MC	500 ft buffer between trenching operations and residences or schools.

MC = Montgomery County Department of Environmental Protection
MSH = Maryland State Health
WRA = Maryland Water Resources Administration
SCS = Soil Conservation Service

There were approximately 719 acres (290 ha) and the land was privately owned. About 41% of the area was wooded; the remaining area was largely agricultural.

11.3.4 Design

The county employed a narrow trench that was 2 ft (0.6 m) wide, 3 ft (0.9 m) deep and varied lengths. The intertrench distance was 2 ft (0.6 m) and cover was mounded 3 ft (0.9 m) over the sludge deposits.

The design and operation insured that the sludge wsa exposed for a minimum time and thus reduced odors, ponding from rainfall, and other undesirable events. Usable areas were defined and mapped during the design process based on soil thickness and depth to groundwater.

11.3.5 Public Participation

11.3.5.1 Public Interaction During the Selection Process

Recognizing the sensitivity of residents to sludge disposal sites, Montgomery County attempted to use education and communication to defuse this volatile issue.

After site selection was performed by a consultant, the county held a public hearing in Rockville, Maryland. Maryland Environmental Services (MES) made a formal presentation on the proposed site, its operation, and impact. They encountered opposition from well-organized community groups based on the fears that the site would generate and release pathogens into local air and water; that the site would be the source of objectionable odors, that deliveries would cause increases in noise and traffic; and that the site would lower property values. The site had previously been considered for a sanitary landfill and the groups involved in protesting the selection were largely an extension of opposition organizations that had formed previously.

The county responded by organizing field trips to the nearby Prince Georges County trenching site. Transportation was provided by the county to all interested residents. Despite these efforts the neighborhood groups filed two suits against the operating agency. Ultimately, the operation was commenced on schedule in February 1976.

11.3.5.2 On-going Public Relations

After commencing operations, a mechanism to provide for continuous communication between MES and the neighborhood group representatives was established. Also, Montgomery County designated one person to personally handle any complaints from neighbors and other county residents.

11.3.6 Operation

The site operated from 7 a.m. to 6 p.m. with the last half hour being used for cleanup only. Following is a discussion of the site preparation and sludge handling procedures during the transfer and on-site phases of the operation.

11.3.6.1 Site Preparation

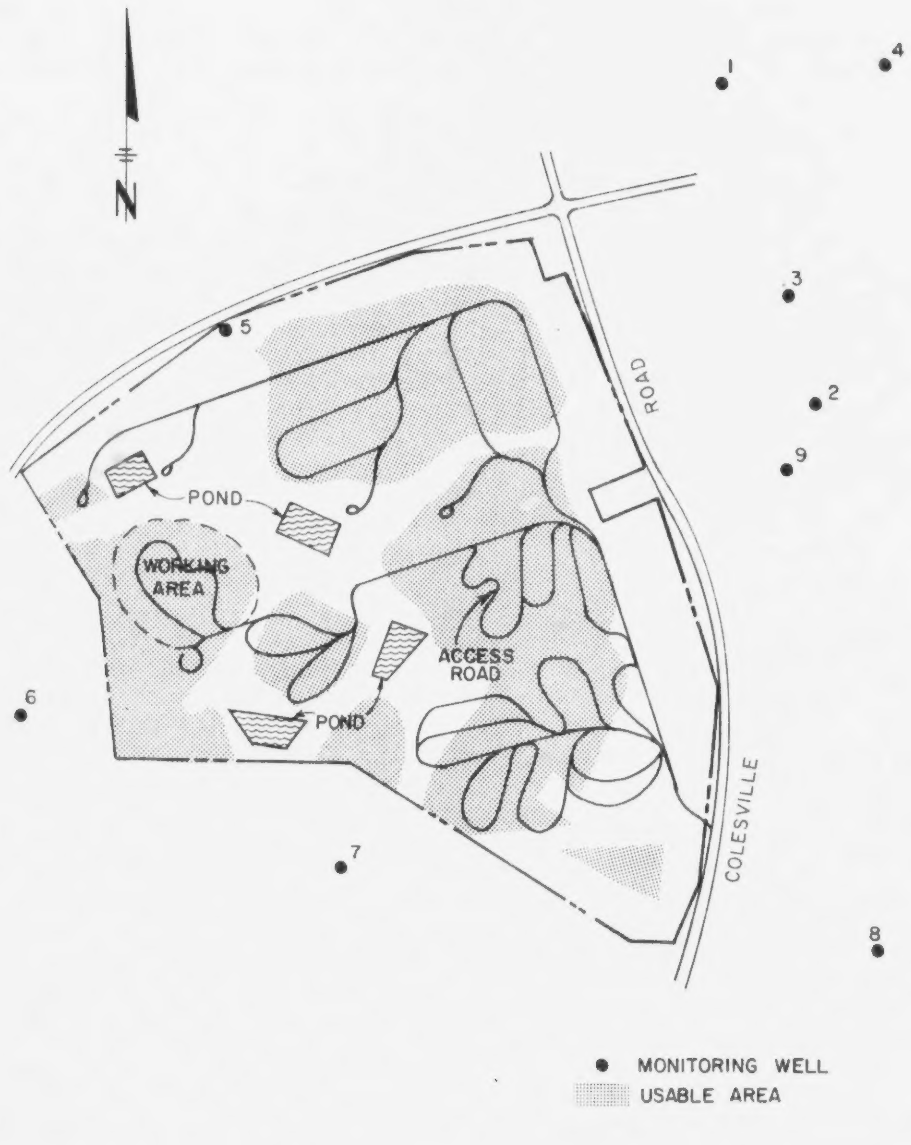
The site did not require extensive excavation, but control of drainage, as in most cases, was critical. Grass diversion ditches, berms, and swales directed runoff into sediment control ponds. All the ponds had risers and were constructed to contain a flood equivalent to the largest 5-yr flood anticipated; two of the five ponds had bentonite liners. Provisions were made to spray irrigate excess pond water as necessary over completed fill areas.

Based on soil cover and depth to groundwater, usable areas were defined. Of the total 719 acres (290 ha), 142 acres (57.5 ha) were estabished as usable and these were scattered throughout the site. Two factors contributed to this relatively low ratio of usable to total acreage. First, narrow trench operations are land intensive and second, much of the land was eliminated because the soil cover was not thick enough to provide the 3 ft (0.9 m) buffer between trench bottoms and groundwater required by the State. Access roads to the usable sites were built to be temporary, with a design life of about one year. As areas were filled, the roads were removed and the material was reused to make new access roads. Figure 11-3 shows the network of roads used during the life of the site.

The entire site was surrounded with a 5 ft (1.5 m) farm fence and the holding ponds were enclosed within a 6 ft (2 m) fence equipped with a 1 ft (0.3 m) barbed extension. There were two wash pads for the trucks. The washing area was contained and runoff was directed to the holding pond. In addition, the facility was equipped with 3 trailers housing administrative offices, showers and restrooms.

FIGURE 11-3

SITE LAYOUT PLAN
MONTGOMERY COUNTY, MD



The design incorporated an extensive odor control system that, in retrospect, did not function adequately. Four in. (10 cm) perforated PVC pipe was installed along the perimeter of the site and in the original plan would have sprayed masking agents when necessary. In practice, site personnel found spray trucks equipped with "Chemscreen" and "Arrest" which sprayed masking agents directly on the sludge to be more effective.

It is projected that the final land use will be agricultural. The site, which closed in February 1978, will remain abandoned and monitored for 5 to 7 yrs.

11.3.6.2 Sludge Loading and Transport

The sludge was loaded on hopper trucks from a railroad car equipped with three augers. The trucks had a capacity of 72,500 lb (32,915 kg) or 31 yd^3 (24 m^3) per truck and included three compartments. The haul distance was 37 mi (60 km) and the total average number of trips per day was 30. Prior to reaching the disposal site, the trucks radioed ahead to alert crews at the disposal area that was currently being used. The operation maintained two disposal areas at all times and used them simultaneously.

11.3.6.3 Operational Procedures

A hose was attached to the top of a hopper truck and the sludge was forced via compressed air applied at a pressure of 20 $lbs/in.^2$ (1.4 kg/cm^2) through a hose from the bottom of the truck into the hopper of a high-powered concrete pump. This pump then forced the sludge through a 200 ft (60 m) long, 5 in. (2.7 cm) diameter flexible hose. The hose, in turn, was guided over the 2 ft (0.6 m) wide trench with a front-end loader.

Simultaneously, the adjoining trench was excavated by a trencher. The machine applied soil from the new trench over the trench receiving the sludge, thus minimizing the time that the sludge was exposed to the air (see Figure 11-4). The receiving trench was mounded to approximately 3 ft (0.9 m). The last trench was covered with soil from another source. Figure 11-5 through 11-7 illustrate the operation.

The access roads were placed in such a way as to maximize the usable areas. In general, the areas were surrounded with two roads joined at the end and separated by about 215 ft (66 m) of usable area. Completed areas were hydroseeded or hand seeded with bluegrass.

FIGURE 11-4

NARROW TRENCH OPERATION
MONTGOMERY COUNTY, MD

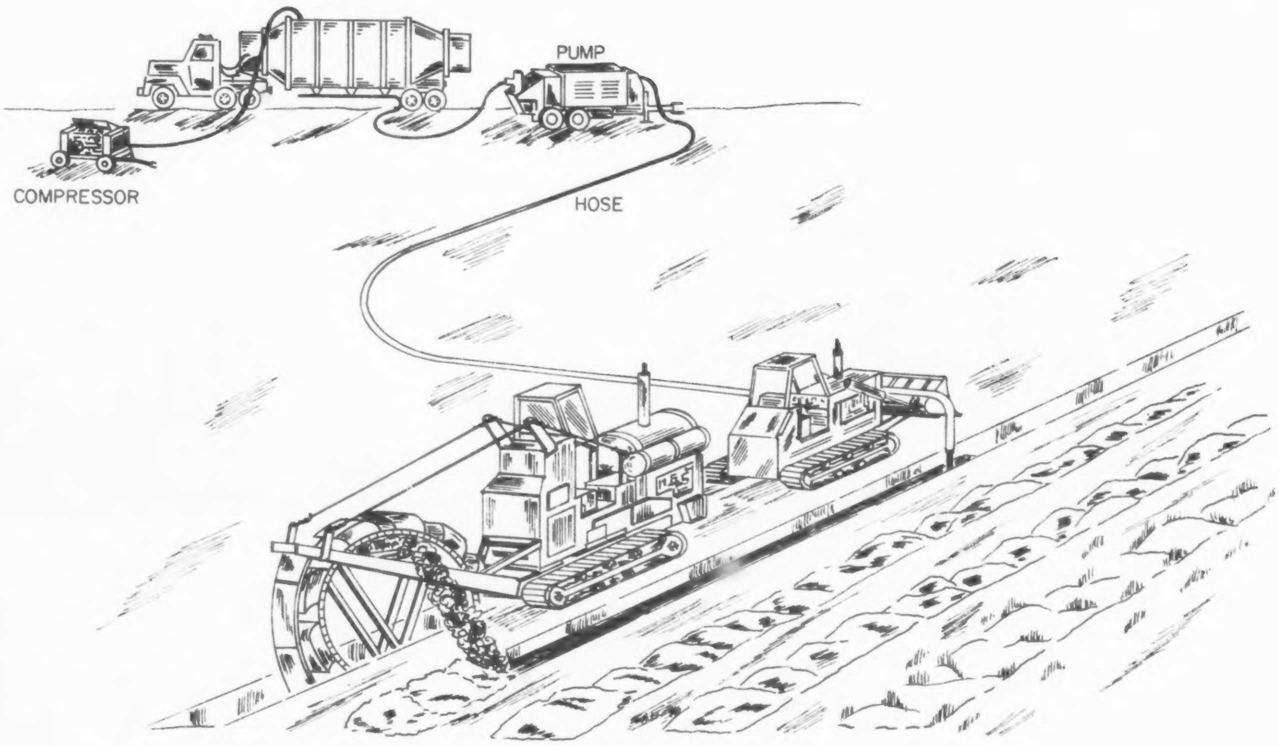


FIGURE 11-5

NARROW TRENCH
MONTGOMERY COUNTY, MD

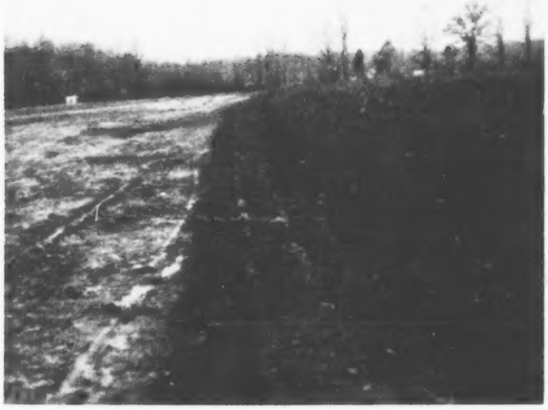


FIGURE 11-6

SLUDGE BEING PUMPED INTO NARROW TRENCH
MONTGOMERY COUNTY, MD

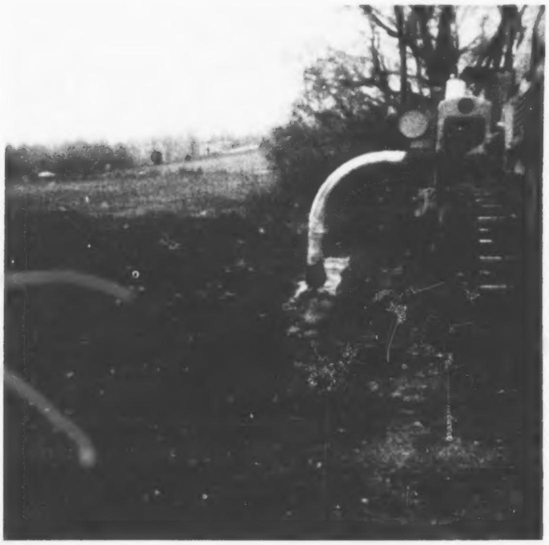


FIGURE 11-7

APPLICATION OF COVER AND EXCAVATION OF NEW TRENCH
MONTGOMERY COUNTY, MD

Relevant operational procedures are summarized below:

- Sludge to groundwater - 3 ft (0.9 m)
- Soil cover thickness - 3 ft (0.9 m)
- Sludge application - 1,275 yd^3/acre (2,400 m^3/ha) (usable area)
- Trench depth - 3 ft (0.9 m)
- Sludge time of exposure - <1 day
- Total soil usage (sludge:soil) - 1:1

The following equipment was used at the facility:

No.	Machine
2	Rotary trenching machines
2	Track type front end loaders
2	Pumps and air compressors
9	Tractors
24	Trailers

Following is an outline of problems, together with solutions, encountered in the operation:

- Frozen ground
  - top 3 ft (0.9 m) of soil was removed and stockpiled
- Possible odors near site
  - lime was placed on spills and masking agents were sprayed from trucks
- Mud and dust
  - mud wash pad at receiving sites used during inclement weather. Water and liquid asphalt sprayed on access roads during dry periods.

11.3.7 Monitoring

The county monitors all wells and surface water within the vicinity of the site for organic and inorganic pollutants. Sampling for the constituents found in Table 11-5 is conducted at a frequency varying from one month to three months depending on the constituents. To date no contamination of surface or groundwater has been noted. The location of the wells is detailed in Figure 11-3.

11.3.8 Costs

The site cost for each wet ton of sludge was \$31.64 (\$34.88/Mg) and each dry ton cost \$143.82 (\$158.57/Mg). Total disposal costs were \$49.54 (\$54.62/Mg) per wet ton of sludge or \$227.07 per dry ton (\$254.00/Mg) of sludge. This relatively high figure reflects the elaborate on-site safeguards and monitoring, the thorough selection process, and the relatively long haul distance. Another factor that contributed to this cost was the high price of land in Montgomery County. A breakdown of on-site and hauling costs is provided below:

	Yd^3	Dry ton	Wet ton
Hauling costs	\$15.92	\$83.25	\$17.90
On-Site costs	\$28.14	\$143.82	\$31.64
Total	\$44.06	\$227.07	\$49.54

TABLE 11-5

SAMPLING AND ANALYTICAL PROGRAM AT MONTGOMERY COUNTY, MD

Monitoring Type	Well/Station No.	Sample Collection Technique	Analyses	
			Parameter(s)	Frequency
Groundwater and surface water	All wells, domestic, on-site area stream station	Have made a sampling device	NO_3, Cd, Cu, Pb, Ni, Cl, Zn, Ca, Total P, Specific Conductants, TDS, TOC	1 month
			Fecal Coliform, Chlor HC, Alk, TKN, NO_2, NO_3, N, SO_4, Mn, Fe, Zn, Cd, Ni, Cu, Pb, Hg, K, Mg, Cr, TOC, NH_3-N, Hardness, Cl, pH, Ts, BOD, COD, PO_4, Ca, Na, Specific Conductance	1/3 month

11.4 Waukegan, Illinois

11.4.1 Background and History

The Newport Township landfill, located near Waukegan, Illinois, receives sludge generated by four treatment plants that serve a domestic population of 232 000 with an additional industrial inflow equivalent to 28 000 residents. The industrial inflow originates primarily from a naval base, a pharmaceutical company and a variety of metal finishing plants. There are three advanced wastewater plants and one pretreatment wastewater plant within the North Shore Sanitary District. The three advanced treatment plants use activated sludge, followed by biological denitrification and sand filtration; the pretreatment plant uses trickling filters. Figure 11-8 and Table 11-6 outlines sludge processing at the wastewater treatment plant. After initial processing, sludge from the four plants is taken to a processing plant in Waukegan where it is elutriated and conditioned with lime and ferric chloride. It is then dewatered to about 22% solids by vacuum filtration (Figure 11-9) prior to landfilling. The site commenced operations on July 8, 1974.

TABLE 11-6

DETAILS ON SLUDGE TRANSPORTED FROM ORIGINATING PLANT TO SLUDGE PROCESSING UNIT AT WAUKEGAN, IL

			Sludge Generation Rate			Transport to Processing Unit	
Plant No.	Plant Name	Sludge Source	lbs per day (dry solids weight)	gallons per day (wet volume)	days per week	mode	transport distance (miles)
1	Waukegan	Primary	13,530	32,446	5	8 in. diameter pipeline	<1
		Waste Activated	15,409	25,177	5	8 in. diameter pipeline	<1
		Imhoff Settling	13.530	27.038	5	8 in. diameter pipeline	<1
2	Clavey Road	(all)	11,968	48,643	5	5,500 gal tank trucks	22
3	Gurnee	(all)	22,965	55,071	5	8 in. diameter pipeline	7.5
4	North Chicago	(all)	1.420	3.405	5	5.500 gal tank trucks	5
TOTAL	--	--	78,822	191,780	--	--	--

1 lb = 0.454 kg
1 gal/d = 3.785 L/d
1 in. = 2.54 cm
1 mi = 1.609 km

FIGURE 11-8

SLUDGE PROCESSING AT ORIGINATING PLANT FOR NORTH SHORE SANITARY DISTRICT

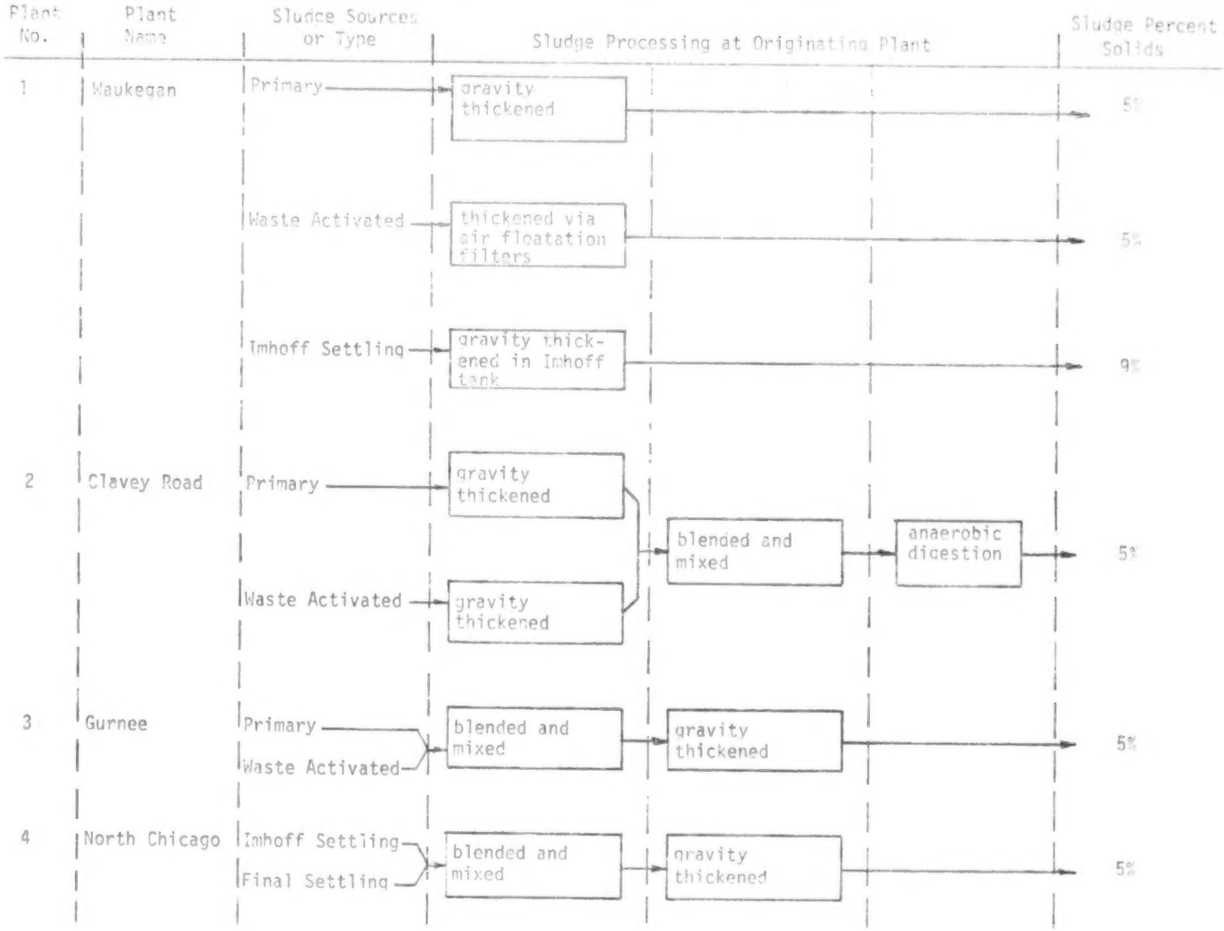
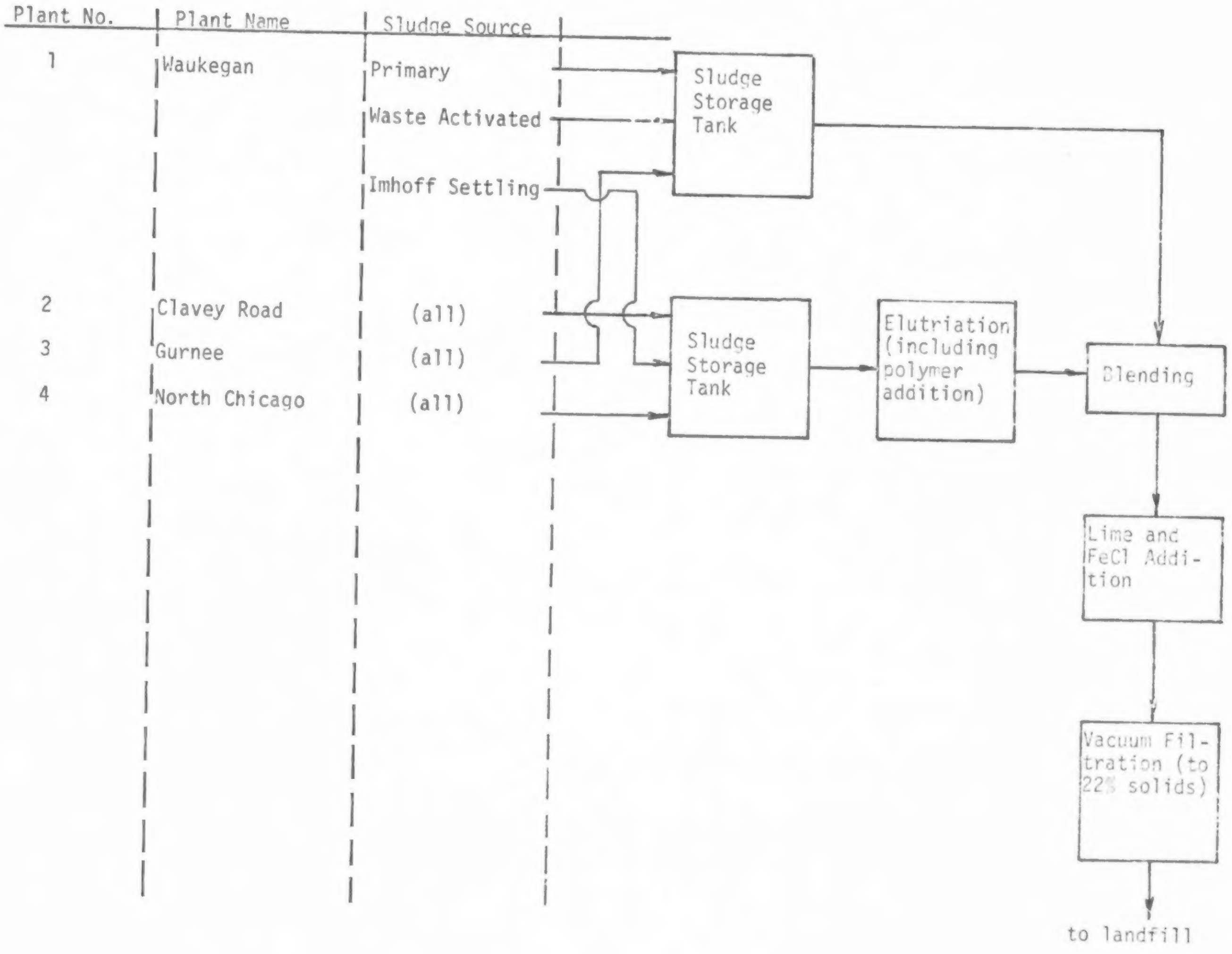


FIGURE 11-9

FLOW DIAGRAM: SLUDGE PROCESSING UNIT AT WAUKEGAN, IL



11.4.2 Site Description

The site has an area of 282.8 acres (114 ha), with 200 acres (81 ha) to be filled. Soils consist of 2 ft (0.6 m) of topsoil, then 20 to 25 ft (6 to 8 m) of silty clays, followed by 6 to 15 ft (2 to 5 m) of tight blue clay. The southwestern part of the site is a flood plain with slopes of less than 1%. The flood plain is not being used for filling operations.

- Topography - slopes average 4%; vegetation sparse; flood plain on west end has 1% slopes
- Soil type - silty clay
- Depth to groundwater - 31 to 40 ft (10 to 12 m); perched table at 25 ft (8 m)
- Groundwater use - aquifer provides potable water
- Freezing days - 140 days per year
- Precipitation - 32 in. per year (81 cm/yr)
- Evaporation - 39 in. per year (99 cm/yr)

11.4.3 Site Selection

The first step in the selection process was to identify the disposal alternatives. The options included:

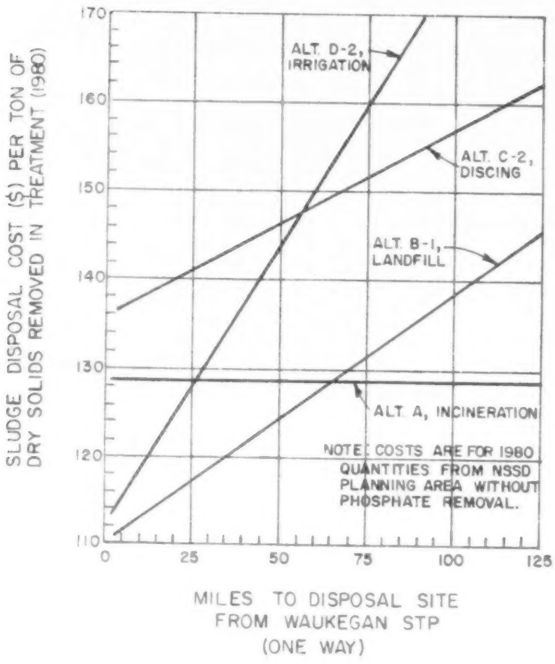
1. Incineration of dewatered raw and digested sludges
2. Disposal of digested, dewatered sludge on cropland by discing or plowing into the soil
3. Disposal of digested liquid sludge on cropland by irrigation
4. Landfilling of dewatered raw and digested sludges

Figure 11-10 illustrates the estimated costs of treatment, transportation and disposal for each alternative. On the basis of these cost evaluations and a maximum distance of 25 mi (40 km) to the landfill, it was determined that sludge landfilling would provide the most cost effective alternative for ultimate disposal.

Following selection of the disposal alternative, eight potential sites were chosen based on available data on soils, geology and topography. Ultimately the Newport Township site was selected for intensive investigation, based on the following considerations:

FIGURE 11-10

COMPARATIVE COSTS OF SLUDGE DISPOSAL
WITHOUT PHOSPHORUS REMOVAL
AT WAUKEGAN, IL



- Short haul distance (10 mi or 16 km)
- Availability of the land for purchase
- A large negative reaction from the public was not anticipated

Accordingly, an option to purchase the land was acquired for this site, and hydrogeological investigations were begun to determine its environmental acceptability. After discussions with the Illinois Sanitary Water Board and the Illinois State Geological Survey regarding the data required to obtain preliminary approval of the landfill site, the District proceeded with the necessary soil borings and laboratory tests. A total of nine borings to a depth of up to 52 ft (16 m) were performed at the site.

By the end of 1970 the District contracted to have topographic maps made of the property. The maps of the 450 acre area were prepared at a scale of 1 in. = 1 000 ft (1 cm = 120 m) and 2 ft (0.6 m) contour intervals. These maps were provided to a consulting engineering firm that the District had contracted to prepare design and operation plans for the site.

11.4.4 Design

The design had to accomodate the following regulatory requirements of the Illinois State Environmental Protection Agency.

- It had to follow the "Rules and Regulations for Refuse Disposal Sites and Facilities" (general operational requirements - no large impacts).
- It was required that a 150 ft (46 m) buffer be placed between sludge deposits and the property line of any residences and the center line of any county roads.
- The site could accept only filter cake sludge conditioned with ferric chloride and lime.
- It was required that groundwater monitoring wells be installed at state-approved locations. Monitoring for 22 contaminants was required annually; 5 parameters quarterly.
- It was required that gas monitoring wells at state-approved locations be monitored for methane, carbon dioxide, nitrogen and oxygen.

Based on information obtained from borings, excavations were limited to a 15 to 20 ft (5 to 36 m) depth. At this depth, at least 20 ft (6 m) of silty clay with a low permeability would separate sludge deposits from groundwater.

Other design considerations included:

- Relatively low solids sludge (22%)
- Deep, well protected aquifer
- Stable soil for trench sidewalls
- Maximum site usage.

As a result of these considerations and the site characteristics, the District chose wide trenches as the disposal method.

In order to determine the stability and seepage characteristics of the soil, the District excavated two test pits on February 9 and 10, 1972.

Each pit was 24 ft by 50 ft (7 m by 15 m) at ground level. The slope of three sides was approximately 1:1, the fourth was 1 horizontal to 2 vertical, with a depth of 12 ft (4 m). All observations indicated that groundwater seepage was not excessive, and that the cuts were stable since no sloughing or caving of the banks was observed.

An application for a permit to install and operate a sanitary landfill, together with a detailed installation and operating plan, was then submitted to the Illinois State Environmental Protection Agency. The permit was issued on March 2, 1972. In September 1973, a contract was awarded by the District for preparation of the site in accordance with plans and specifications prepared by the consultant.

11.4.5 Public Participation

11.4.5.1 Public Interaction During Site Approval

Although when the District initially selected the site they anticipated little public resistance, protests began following reports of the proposed landfill operation in the media. However, the District performed detailed environmental impact investigations and prepared an operational plan designed to minimize impacts. The District worked closely with various regulatory authorities including:

- Illinois State Environmental Protection Agency
- U.S. Department of Agriculture, Soil Conservation Service
- Lake County Illinois Soil and Water Conservation District

These authorities reviewed and provided input to site plans and reports throughout the process and as a result of their support, the public reaction became less negative.

11.4.5.2 On-going Public Relations

Operational features designed to minimize public resistance were:

- Application of cover over sludge throughout the day in warm weather to minimize odors.
- Application of lime over sludge in haul vehicles at all times to minimize odors.

As a result, the only complaints received to date have been from a resident whose property is literally surrounded by the landfill. The resident's complaints are generally justified, and they have been constructive in nature. In general, they have centered on odors and noise; consequently, dumping and operating procedures have been restricted and currently run from 7 a.m. to 4 p.m.

11.4.6 Operation

Site preparation, sludge loading and transport, and the operating practices employed are discussed in sections 11.4.6.1, 11.4.6.2, and 11.4.6.3, respectively. Operational considerations are presented below:

- Sludge to groundwater - >10 ft (>3m)
- Soil cover thickness - 5 ft (1.5 m)
- Sludge application - 9,100 yd^3/acre (17,200 m^3/ha)
- Fill depth - 14 ft (4 m)
- Sludge exposure - <1 day
- Total soil usage (sludge:soil) - 1:0.6

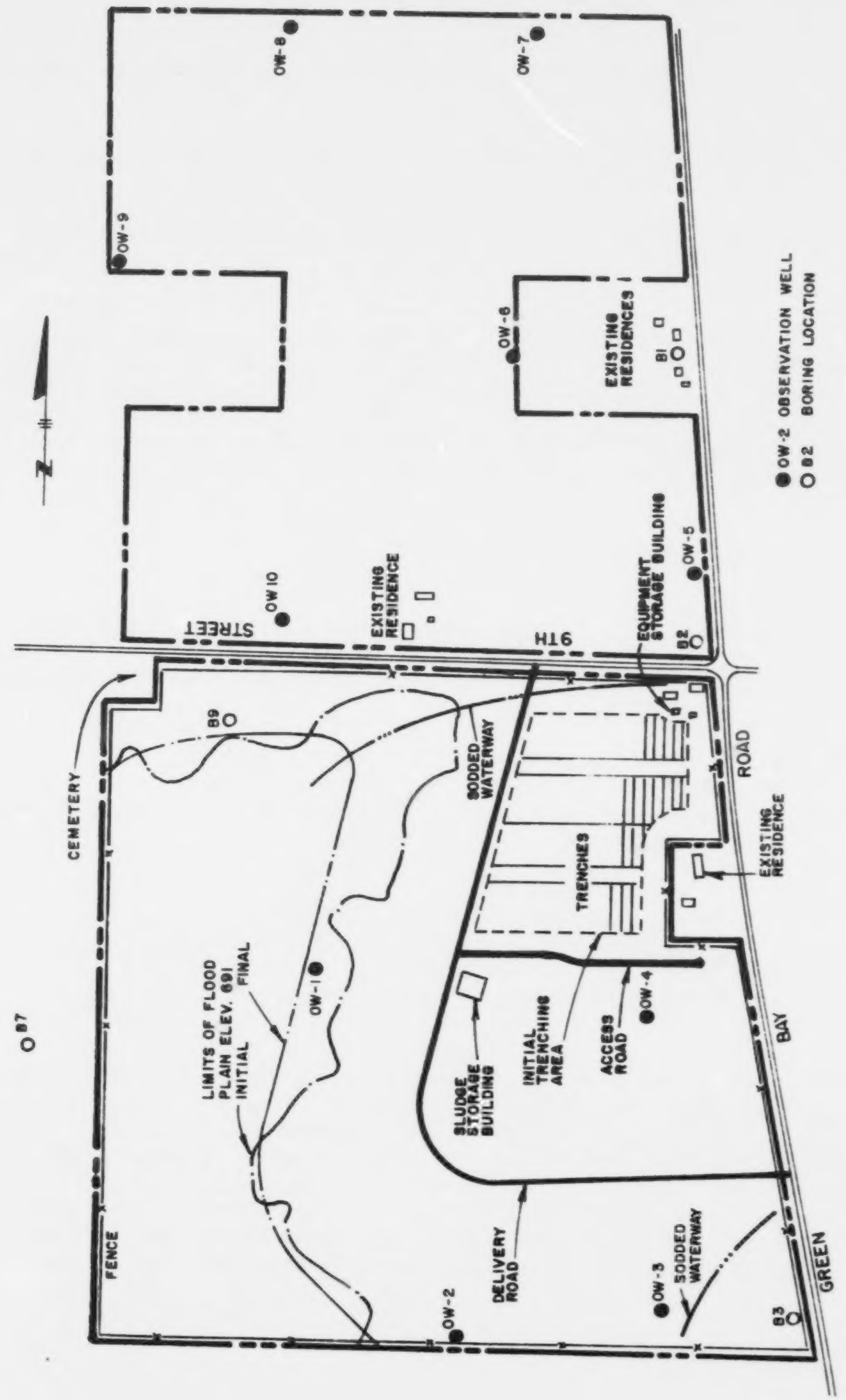
11.4.6.1 Site Preparation

The existing on-site barn, silo, and minor out-buildings were demolished. The remaining farmhouse was used as an office. Structures for storing sludge and on-site equipment were constructed. A paved, all weather access road was constructed to within several hundred feet of the disposal area. Approaches to the disposal areas were covered with sand and gravel. A 6 ft (2 m) fence was provided for the area south of Ninth Street (Figure 11-11). Lighting was installed around on-site structures and sewer, water, and telephone services were in place at the farmhouse.

Prior to excavating a trench the top 3 ft (0.9 m) of soil was stripped and stockpiled.

FIGURE 11-11

SITE LAYOUT PLAN
WAUKEGAN, IL



11.4.6.2 Sludge Loading and Transport

Sludge from the vacuum filter at the Waukegan sludge processing unit is transported via a conveyor belt that moves from end to end of a 30 yd^3 (23 m^3) open dump truck. Thus, sludge is spread evenly over the bed of the truck. There are five open-top dump trucks with sealed tailgates, and each makes about 5 trips to the landfill each day. The one-way haul distance is 10 mi (16 km) and the haul roads are suitable for truck traffic.

11.4.6.3 Operational Procedures

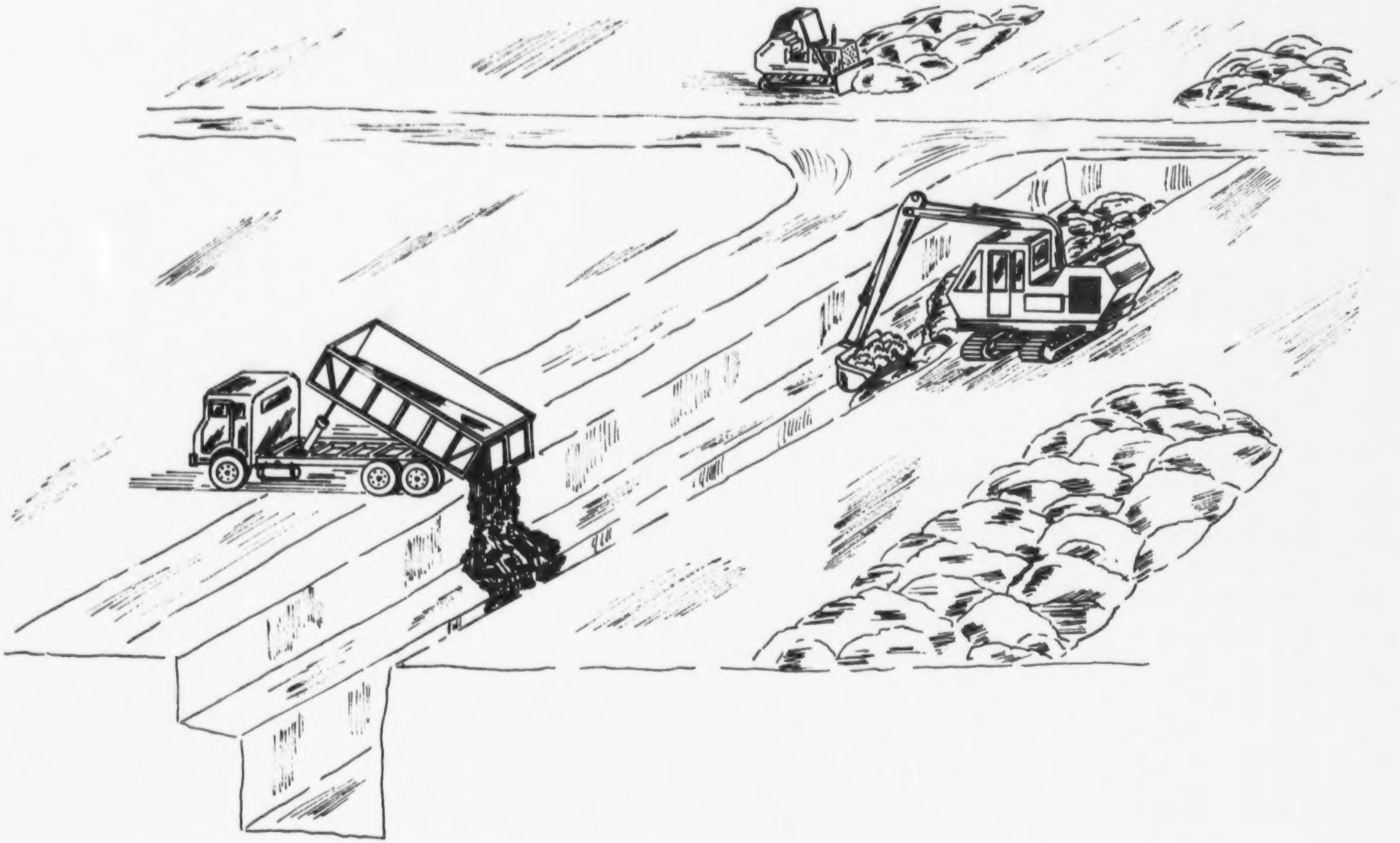
Individual trenches 20 ft deep, 70 ft long and 22 ft wide (6 m deep, 21 m long, and 7 m wide) at the top are excavated by a large backhoe/excavator. Sidewalls are straight on all but one side; the 70 ft (21 m) length on the side where dumping is done has a 6 ft (2 m) wide step halfway down for added sidewall stability. Thus, the bottom trench width is 16 ft (5 m). Consecutive trenches are constructed with the 70 ft (21 m) sides parallel. Twenty ft (6 m) of solid ground is maintained between the parallel trenches and consecutive trenches proceed in a line to form a single row (Figure 11-11). After completion of one line of trenches, a second line is begun (as shown in Figure 11-12) to the side of the first line. Five ft (2 m) of solid ground is maintained between adjacent rows. The trenches are graded so that leachate can be collected at one end of the trench and returned to the Waukegan plant for treatment. Haul vehicles back up on prepared sand and gravel access roads to the long sides of each trench, and sludge is dumped by the trucks in progression from one end of the 70 ft (21 m) length to the other.

Usually the consistency of the sludge is such that it flows out to an even grade inside each trench. However, the bucket of the backhoe/excavator is used to spread the sludge evenly at the end of the day. One day's sludge usually accumulates to a 2 ft (0.6 m) thickness. Filling proceeds to within 2 ft (0.6 m) of the surface before proceeding to a new cell.

At the end of each day, a 6 to 8 in. (15 to 20 cm) soil cover is applied over the sludge. After filling has proceeded to within 2 ft (0.6 m) of the subsurface (usually at the end of a week), a 5 ft (2 m) cap of topsoil cover (previously stockpiled) is applied to 3 ft (0.9 m) above grade by the backhoe. After initial settlement the trench is final graded and compacted with small bulldozers (including a D-3 and a D-5). Additional operational characteristics are detailed below:

FIGURE 11-12

WIDE TRENCH OPERATION
WAUKEGAN, IL



The equipment and personnel at the site are as follows:

- Equipment

  1 - Backhoe/Excavator (Northwest with 1.5 yd^3 bucket)
  1 - Front-end Loader (Hough with 2 yd^3 bucket)
  1 - Bulldozer (Caterpillar D-3)
  1 - Bulldozer (Caterpillar D-5)

- Personnel

  1 - Superintendent
  3 - Equipment Operators
  1 - Laborer

Problems encountered during the operation of the landfill, together with controls are detailed below:

- Problem: Freezing temperatures make excavation of cells and placement of stockpiled cover impossible. Snow and rain make access to cells by haul vehicles and site operation by equipment difficult.

  Control: During inclement weather, soil is stockpiled on the site inside a sludge storage building accessible via paved roads. This building is a steel frame structure 50 ft by 50 ft by 30 ft (15 m by 15 m by 9 m) high. It is constructed on a concrete slab with concrete sidewalls extending 3 ft (0.9 m) high. A trench drain is located in the middle of this slab to collect sludge moisture. This leachate is directed to an underground 10,000 gal (37,850 l) storage tank. Leachate is pumped out of the tank as necessary and transported via tank truck to the Waukegan Plant for treatment. In poor weather, all sludge delivered to the site is dumped into the building which prevents the addition of moisture from precipitation and controls odors. When weather improves, the sludge is loaded back into dump trucks with front-end loaders and hauled to the cells.

- Problem: Soil runoff from denuded fill areas.

  Control: Fill areas are seeded with grasses soon after completion. All on-site drainage is channeled through sod-lined ditches to a collection pond.

- Problem: Odors from sludge during transport, from uncovered sludge in cells during warm weather, from sludge spills, and from equipment.

  Control: Initially sludge transport was to be in dump truck trailers covered with tarpaulins for odor control. However, this caused operational difficulties and transport is now accomplished in open-top trucks. However, after loading, the sludge is covered with a layer of lime for odor control while in transit. In warm weather, sludge in the cells is covered during the day as well as at the end of the day. Lime is sprinkled over any sludge spills. The backhoe bucket (which comes into contact with sludge) is buried in soil at the end of the day to minimize odors.

- Problem: Mud from site is tracked onto adjoining roadways by haul vehicles.

  Control: A washrack is located at the Waukegan Sludge Processing Unit. It is used to clean haul vehicles in wet weather.

- Problem: Noise of haul vehicles and on-site equipment bothers near-site residents.

  Control: Per agreement with nearby residents, hauling and operation is confined to between 7 a.m. and 4 p.m.

Figures 11-13 through 11-16 illustrate equipment and operations at the Waukegan site.

11.4.7 Monitoring

Background samples were taken from all wells prior to initiating operations so that baseline conditions could be established. Subsequent monitoring has not detected any contamination of groundwater in on-site wells nor has water from the collection pond and drainage ditches contaminated surface waters. Establishing initial conditions proved valuable since one of the local potable wells showed contamination that could have been attributed to sludge disposal but was known to precede disposal operations as a result of initial tests.

The number, location, and function of the monitoring wells was established in conjunction with the Illinois State Environmental Protection Agency. Figure 11-11 illustrates the location of the wells and Tables 11-7, and 11-8 detail the wells and monitoring parameters.

FIGURE 11-13

STOCKPILING SOIL
WAUKEGAN, IL

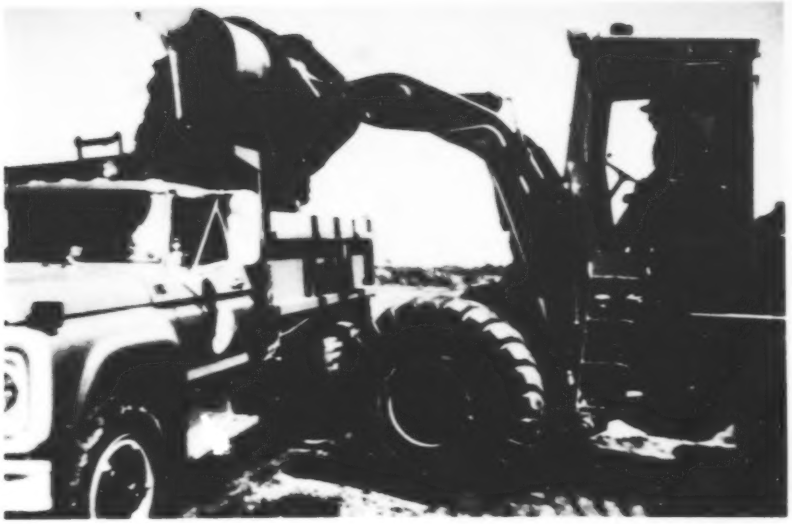


FIGURE 11-14

UNLOADING SLUDGE INTO WIDE TRENCHES
WAUKEGAN, IL

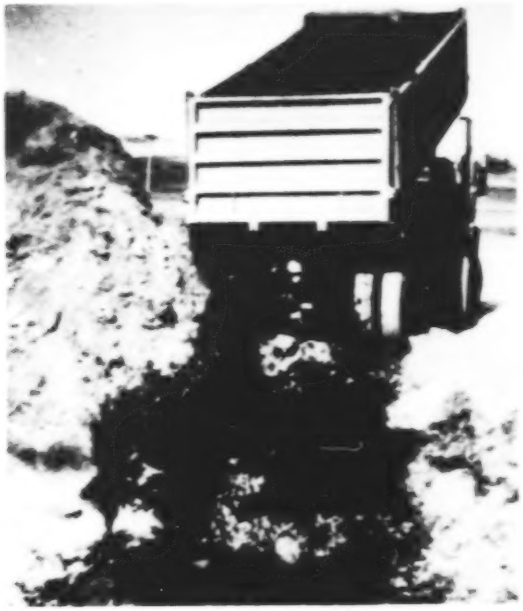


FIGURE 11-15

PLACING INTERIM COVER
WAUKEGAN, IL

FIGURE 11-16

PLACING FINAL COVER
WAUKEGAN, IL

TABLE 11-7

SUMMARY OF GROUNDWATER AND GAS WELLS AND SURFACE WATER STATIONS AT WAUKEGAN, IL

		Relation to Fill		Well Specifications		
Monitoring type	Well/station no.	Location (up- or down-gradient)	Distance (ft)	Total depth (ft)	Depth below groundwater (ft)	Drill rig used
Groundwater	OW-1	Down-gradient	200	30	5	Auger
	OW-2	Down-gradient	100	30	5	Auger
	OW-3	Up-gradient	100	30	5	Auger
	OW-4	Up-gradient	20	30	5	Auger
	OW-5	Up-gradient	100	30	5	Auger
	OW-6	Up-gradient	100	30	5	Auger
	OW-7	Up-gradient	100	30	5	Auger
	OW-8	Down-gradient	100	30	5	Auger
	OW-9	Down-gradient	100	30	5	Auger
	OW-10	Down-gradient	100	30	5	Auger
	5 Potable Wells	Down-gradient	<1/2 mi	--	--	--
Gas	Gas Well 1	In-sludge	--	--	--	--
Leachate	Sludge cell	--	--	--	--	--
	Tank under sludge storage building	--	--	--	--	--
Surface Water	Runoff pond	--	--	--	--	--
	Drainage ditches	--	--	--	--	--

1 ft = 0.305 m

TABLE 11-8
SAMPLING AND ANALYTICAL PROGRAM AT WAUKEGAN, IL

Monitoring type	Well/station no.	Sample collection technique	Analyses Parameter(s)	Total times to date	Frequency
Groundwater	OW-1 OW-2 OW-3 OW-4 OW-5 OW-6 OW-7 OW-8 OW-9 OW-10 5 potable wells	10 ft length of 1-in. diameter PVC pipe, fitted with polyethylene foot valve on bottom	22 parameters including metals as dictated by State EPA Fecal coliform	3 about 100	1 x per yr 2 x per mo
Gas	Gas Well 1	gas cylinder	CO_2, O_2, N_2, CH_4, COS, H_2S, SO_2	about 20	2 x per mo
Leachate	Sludge cell Tank under sludge storage building	grab sample	Fecal coliform	about 20	irregularly
Surface Water	Runoff pond Drainage ditches	grab sample	Fecal coliform	about 20	irregularly

11.4.8 Costs

A breakdown of the on-site costs reveals that the cost per dry ton of sludge was $10.61 ($11.70/Mg). The costs were calculated in the following manner: first capital expenditures were divided by the total amount of sludge received over the life of the site; next operating costs were divided by the amount of sludge received for the period considered (6 months in this case); finally the figures were added to arrive at the total cost per unit of sludge (excluding hauling costs). The intensive use of the available land contributed to this relatively low figure. The following tabulation is a breakdown of the costs by category. Hauling costs have not been included in the total cost.

	Total Cost ($)	Unit Cost ($/dry ton sludge)
Site Capital Costs		
Land	$ 450,000	$2.25
Monitoring Wells	12,000	0.06
Site Preparation	328,000	1.64
Total Capital Cost	$ 790,000	$3.95
Site Operating Cost (October 1977 through March 1978)		
Labor	$ 18,200	$3.64
Equipment Depreciation	16,450	3.29
Administration	7,300	1.46
Maintenance	6,850	1.37
Laboratory	1,450	0.29
Fuel	1,250	0.25
Operating Materials & Supplies	900	0.18
Miscellaneous	650	0.13
Total Site Operating Cost	$ 53,050	$10.61

11.5 Colorado Springs, Colorado

11.5.1 Background and History

The Colorado Springs landfill is located on Drennan Road near Peterson Field. The operation uses two landfilling methods: narrow trench and wide trench. The focus of this study will be restricted to the wide trench operation. The current flow of the treatment plant is 24 Mgal/d (1.1 m^3/s) and the plant is designed to handle up to 30 Mgal/d (1.2 m^3/s) from a population of 230,000. Industrial impact is presently being studied, but Colorado Springs does not require pretreatment of industrial effluents at present. In general, the sludge has a lower heavy metals content than typical municipal sludge. The treatment plant has bar screen separation, primary clarifiers, and waste activated sludge treatment. Using gravity thickening and vacuum filtration the sludge is dewatered to about 20 to 25% solids. Although the site began operations in 1970, wide trench disposal did not begin at the site until July 1976 and terminated on December 19, 1977.

11.5.2 Site Description

- Topography - rolling hills <8 % slopes
- Groundwater use - windmill aquifer - provides drinking water
- Soil type - silt and clay
- Depth to groundwater - >10 ft (>3 m)
- Freezing days - 120/yr
- Precipitation - 13 in./yr (51 cm/yr, mostly snow)
- Evaporation - 60 in./yr (152 cm/yr)

11.5.3 Site Selection

The Peterson Field site was selected because it offered significant advantages:

- Extended site life
- Land was owned by the city
- Short haul distance
- Site was fenced and area was sparsely populated

After the selection was made operations were begun immediately. There were no further selection criteria considered and no preparation of design or operation reports. Interaction with local, state and federal government was limited. Although not employed as selection criteria, both the amount of soil available and the topography were favorable for landfilling.

11.5.4 Design

There were no design plans or site alterations made prior to initation of operations since the site was relatively flat and required no alterations. Wide trench operations were restricted to upland areas and surface runoff was controlled by the orientation of trench and fill (outlined in more detail in Operation 11.5.6).

11.5.5 Public Participation

Public interaction did not begin until a few years after the opening of the site, when a housing development was built near the site and along the haul route. The residents complained of odors from accumulated sludge piles. Following those complaints city officials instructed site personnel to cover sludge as it was received. However, complaints continued from both nearby residents and airport officials. Accordingly, city officials decided to relocate the site in December 1977, despite the fact that a considerable amount of usable area remained.

11.5.6 Operation

The site operated 7 days a week from 6 a.m. till 10 p.m. The wide trench operation received a total of 6,200 dry tons (5,624 Mg) of sludge with a solids content of 22% over the 17-month life of the operation. Site preparation, sludge transport and disposal operations are discussed in the following sections.

11.5.6.1 Site Preparation

Fencing and other facilities were in place at the inception of the disposal operation. The site's topography was compatible with the disposal method and vegetation was sparse; consequently excavating and grubbing were not necessary. Preparation consisted mainly of digging the wide trenches. Contractors did the excavations which were 60 to 80 ft wide (18 to 24 m); 600 to 800 ft (183 to 244 m) long; and 6 to 8 ft (2 to 2.5 m) deep. The trenches were located on upland areas with the long axis of the trench perpendicular to the slope. The location of these pits on high ground, and the soil stockpiles on the uphill side prevented accumulation of water. Between 20 and 25 ft (6 to 8 m) of ground separated the trenches.

11.5.6.2 Sludge Loading and Transport

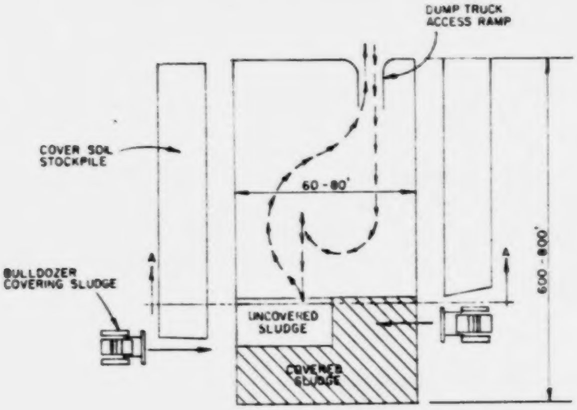
The one-way haul distance was 7 mi (11 km) and the roads were compatible with heavy truck traffic. In addition, the route traversed a rural area and minimized the impact of transport on residents. The sludge was placed into uncovered dump trucks with sealed tailgates and varying capacities directly from the vacuum filters. The three vehicles made a total of ten trips per day.

11.5.6.3 Operating Procedures

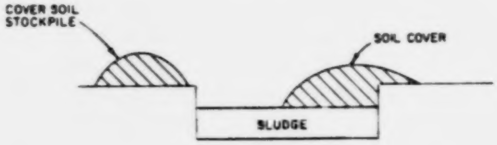
Dump trucks hauling sludge entered the trenches through the ramps and deposited sludge at the opposite end as shown in Figure 11-17 and 11-18. Dumping took about 2 or 3 minutes maximum for each load. Each load was dumped on fresh ground. That is, sludge loads were not dumped atop previous loads. Typical pile heights were 4 ft (1 m).

FIGURE 11-17

SCHEMATIC OF OPERATING PRACTICES
AT COLORADO SPRINGS, CO



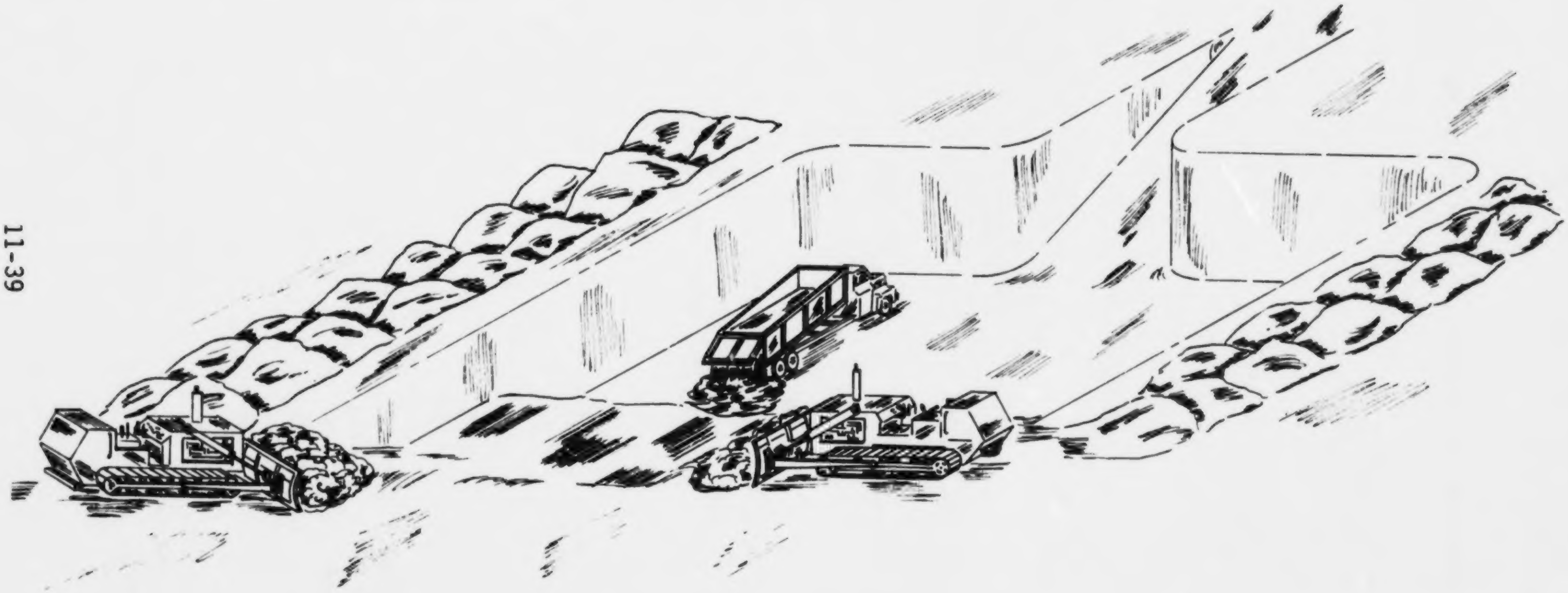
PLAN VIEW



SECTION A-A

Two bulldozers applied daily cover over sludge piles. Usually one dozer pushed the cover soil stockpiled on one long side of the trench out over the 4 ft (1 m) high sludge piles, while the other dozer pushed the cover soil from the other long side. Cover was usually graded 4 ft (1 m) thick (see Figure 11-17 and 11-18).

FIGURE 11-18



WIDE TRENCH OPERATION
COLORADO SPRINGS, CO

It was found that this thickness was required before the soil could safely support equipment.

Additional operating characteristics are detailed below.

- Sludge to groundwater - >5 ft (2 m)
- Soil cover thickness - 4 ft (1 m)
- Sludge application - 4,700 yd^3/acre (8,883 m^3/ha)
- Fill depth - 4 ft (1 m)
- Sludge exposure (days) - <1 day
- Total soil used (waste:soil) - 1:1

The information below outlines the equipment and personnel required to operate the site.

Equipment	Time	Personnel
Caterpillar D-6	1/2 (20 hrs/wk)	1/2
Caterpillar D-8	1/2	1/2
Scraper	1/4 (10 hrs/wk)	1/4
TOTAL	1-1/4 (50 hrs/w)	1-1/4

The equipment used was not specifically selected for this operation, but was chosen from available equipment already owned by the municipality and was used for both narrow and wide trenching and occasionally, other operations.

The only facilities located on the structure were a camper shell and chemical toilet.

Following is an outline of problems associated with the operation of the site and the controls used:

- o Problem: Wet and snowy weather causes access problems for haul vehicles. Access roads on the site are dirt (not paved) and become slippery or muddy (in snowy or wet weather, respectively). Driving loaded trucks on public paved roads in such weather is also hazardous. This has resulted in several small accidents in the past.

  Control: Hauling is discontinued and site closes down in severe weather. This happens for an average of 10 days each year. The treatment plant has about 30 to 40 days storage capacity for sludge when the site is closed. Further, contractors can be used and have been used to haul the backlog of sludge when site operations resume.

- Problem: Despite daily cover, because sludge is not digested or otherwise stabilized, odor can be a problem in warm weather and complaints are received from nearby residents.

  Control: Cover was applied several times during the course of the day in warm weather.

- Problem: Rainfall which collects in the pits caused problems with haul vehicles becoming stuck in the mud. Dust was a problem in dry weather and nearby residents complained regularly.

  Control: A layer of fresh dry soil was applied in the pits to improve maneuverability by haul vehicles in wet weather. A water tank truck with a spray bar was used to apply water to on-site dirt roads in dry weather.

- Problem: Strongest complaints from nearby residents concerning the subject site were directed at noise from equipment and from haul vehicles on the site, and increased traffic from haul vehicles on public roads.

  Control: None practiced to date. Public officials attempted to placate nearby residents by assuring them that the disposal operation were soon to be dis con inued at the site.

- Problem: Flies were attracted to and breed in sludge at the site. Nearby residents complained, particularly in warm weather.

  Control: Sludge was sprayed with a disinfectant in the summer to keep the flies down. This disinfectant is the type normally used on livestock to protect them from flies.

Figures 11-19 and 11-20 illustrate the operational procedures at the site.

11.5.7 Monitoring

Several months after the site was established, the city began to monitor existing on-site wells to determine the impact of the site, if any, on the Windmill Aquifer. This was motivated by a desire on the part of city officials to allay public concern and hence extend the site life. Figure 11-21 shows the location of the monitoring wells.

FIGURE 11-19

WIDE TRENCH
COLORADO SPRINGS, CO

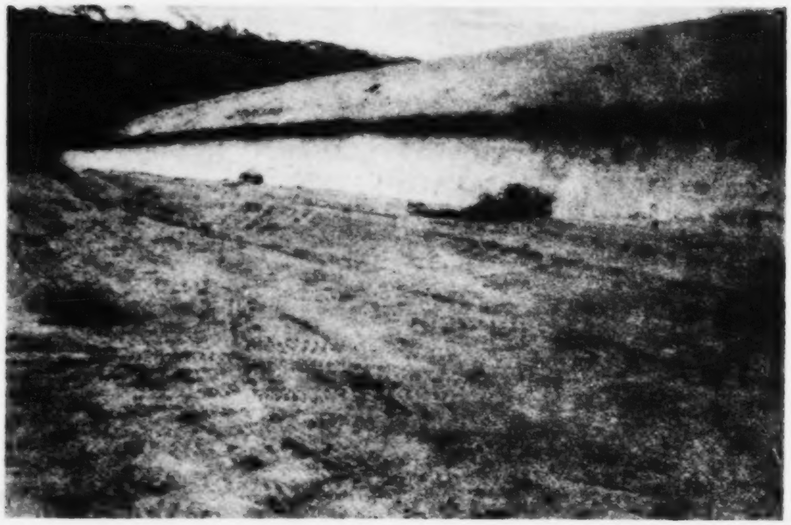


FIGURE 11-20

APPLYING COVER TO SLUDGE DEPOSITS
COLORADO SPRINGS, CO

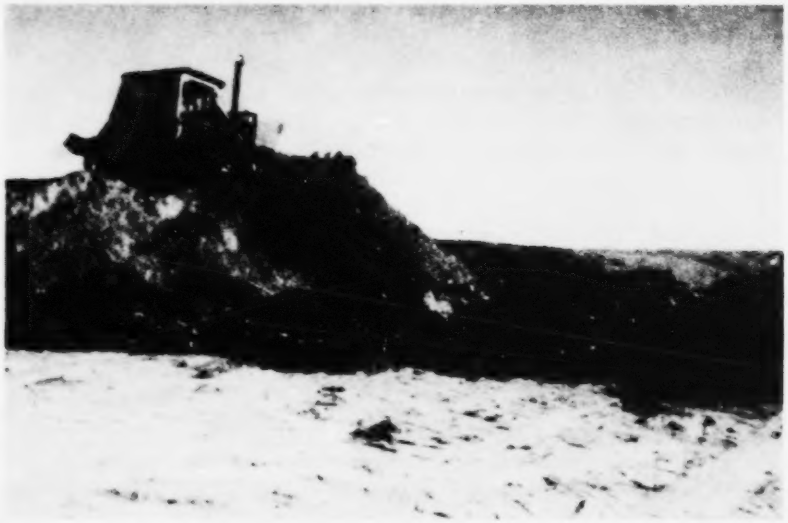
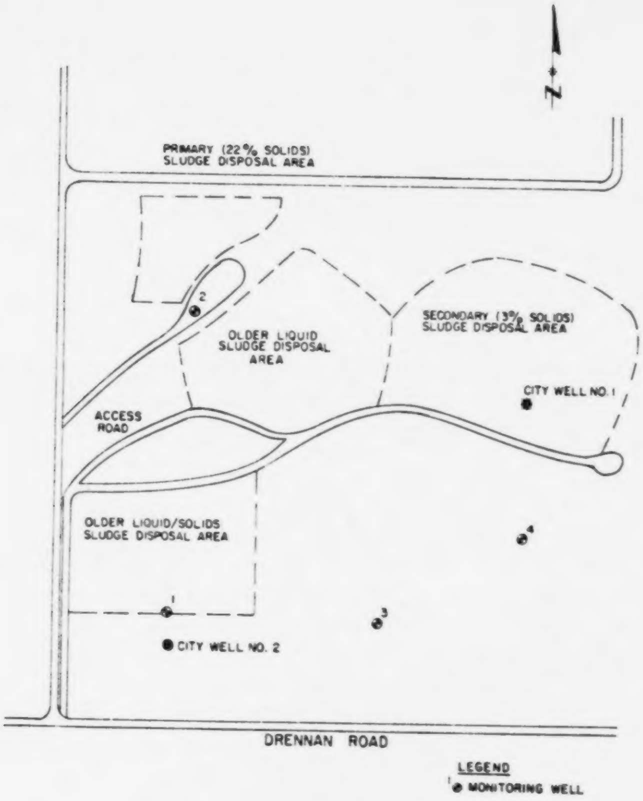


FIGURE 11-21

SITE LAYOUT PLAN
AT COLORADO SPRINGS, CO


N
PRIMARY (22% SOLIDS) SLUDGE DISPOSAL AREA
2
OLDER LIQUID SLUDGE DISPOSAL AREA
SECONDARY (3% SOLIDS) SLUDGE DISPOSAL AREA
CITY WELL NO. 1
ACCESS ROAD
4
OLDER LIQUID/SOLIDS SLUDGE DISPOSAL AREA
1
3
CITY WELL NO. 2
DRENNAN ROAD
LEGEND
MONITORING WELL

11.5.8 Costs

The total cost per dry ton of sludge including hauling costs was \$25.32 (\$27.92/Mg). The costs were derived by dividing the quantity of sludge received in a year by the annual haul and operating costs. Site costs were significantly reduced since the land was owned by the municipality initially. Also, investigations indicated that extensive environmental controls were not necessary. Together with the short haul distance these factors contributed to the low handling costs outlined below.

	Total Cost ($)	Unit Cost ($/dry ton)
Haul Cost	$ 87,600	$20.00
Site Capital Costs (None since land was free)		
Site Operating Cost		
Equipment and Personnel for Trench Excavations	$ 7,700	$ 1.76
Equipment and Personnel for Covering Pits	$ 15,600	$ 3.56
Total Site Operating Cost	$ 23,300	$ 5.32
Total Cost	$110,900	$25.32

The costs presented are based on the operating cost of the landfill for a single year and the total amount of sludge received (4,380 dry tons (3,970 Mg)) for a one year period.

11.6 Denver, Colorado

11.6.1 Background and History

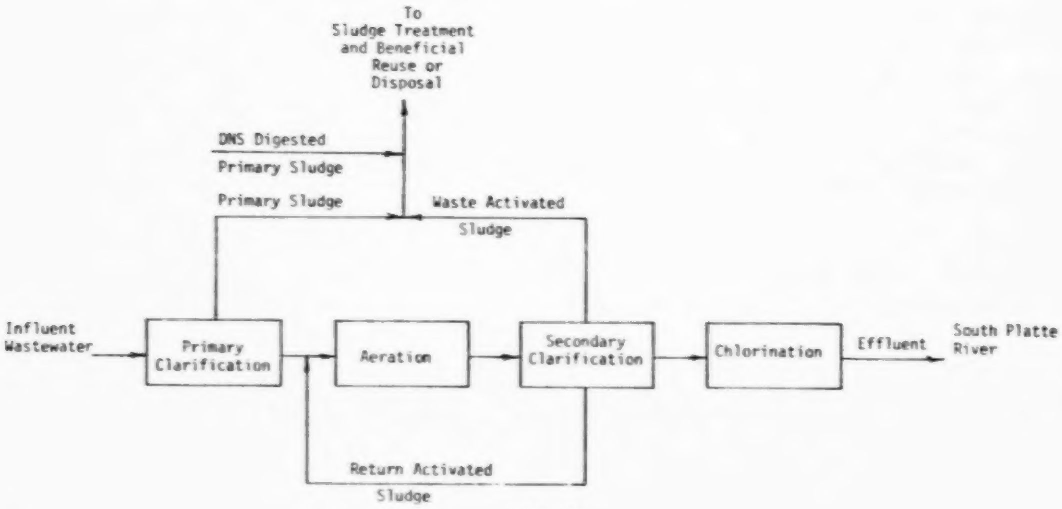
The Denver disposal site is located 26.2 mi (42 km) southeast of the Metro treatment plant off state highway 30 in the Lowery Bombing Range (LBR). The plant processes approximately 100 Mgal/d (4.4 m^3/s) and serves a population of 1,100,000. About 15% of the inflow is from industries, including slaughter houses, plating industries, chemical manufacturers, and office buildings. The plant produces thickened waste activated sludge (WAS) and the Denver Northside (DNS) treatment plant contributes primary digested sludge. This mix is pumped to a processing building where lime, ferric chloride and/or polymers are added to aid vacuum filtration. The sludge has a 15% solids content and the plants contribute 100 dry tons (90 Mg) per day with the following constituents:

- Raw primary - 40%
- Anaerobic, digested - 15%
- WAS, digested - 45%
- $FeCl_3$ - 8-12% dry weight
- Lime - 20-30% dry weight

Figure 11-22 outlines the treatment processes and sludge characteristics of contributing plants. The site uses two disposal methods; the primary disposal method is an application technique that incorporates the sludge into the soil by cultivation. The alternate method, area fill using layering, is employed in cold weather. This technique was initiated in 1973 and will be the focus of this case study.

FIGURE 11-22

WASTEWATER TREATMENT FLOW DIAGRAM
FOR DENVER, CO METRO PLANT



11.6.2 Site Description

The site has a total area of 1,450 acres (587 ha) and 650 acres (263 ha) are being used for the area fill operation. The climatic and physiographic characteristics at the site are detailed below.

- Topography - gently rolling hills; low relief
- Soil type - clay, sand and gravel
- Depth to groundwater - 10 to 140 ft (3 to 43 m)
- Groundwater Use - aquifer provides potable water
- Freezing days - 240/yr
- Precipitation - 14 in./yr (36 cm/yr)
- Evaporation - 60 in./yr (152 cm/yr)

11.6.2.1 Soils and Geology

The surficial geology of the area consists of two principal units: (1) alluvium consisting of unconsolidated, poor- to moderately well-sorted clay, silt, sand, and gravel of Pleistocene and Holocene age with a maximum thickness of about 25 ft (7.6 m); and (2) the undifferentiated Denver and Dawson Formations consisting of brown, dusky-yellow, and blue-gray mudstone with thin, lenticular beds of lignite and gray sandstone.

The dominant soils at the LBR are the Fondis and Renohill series. The Fondis soils are deep well-drained soils located on uplands, and formed from loessol deposits overlying the Dawson formation (Pleistocene Age). The Fondis surface soil is about 10 cm thick, free of lime, very dark grayish-brown and silt loam or silty clay loam in texture. The subsoil is 41 to 46 in. (102 to 114 cm) thick, contains free lime, is dark yellowish brown in color and silt loam to clay in texture. The Fondis soils have a moderately slow permeability, slow internal drainage and high available water holding capacity. The Renohill series which has developed on the Dawson formation is a moderately deep well-drained soil. The surface layer is about 4 in. (10 cm) thick, free of lime, and is dark brown loam. The subsurface soil is approximately 25 in. (63 cm) thick, contains free lime, dark brown to dark yellowish brown in color, and ranges from a loam to silty clay loam in texture. Renohill soils have medium internal drainage, moderately slow to slow permeability and moderate water holding capacity.

11.6.3 Site Selection

No site selection process was employed. The city of Denver purchased the land in the 1950's from the Federal government for the expressed purpose of solid waste disposal. In 1969, Metro acquired disposal rights to the land from the city and county of Denver. As a result, no pre-selection investigations were conducted.

11.6.4 Design

There was no design process, but through trial and error two operating methods were established. The first was a land application method, the second an area fill procedure used only in inclement weather. The topography of the site was conducive to both disposal and application.

11.6.5 Public Participation

Due to the remoteness of the site there was no interraction with the public during the site approval phase. Beginning in 1972, complaints were registered by residents who lived near LBR.

As a result, the Arapahoe County commissioners conducted a public hearing and invited Metro to attend. The complaints centered on objectionable odors associated with the site. These were a consequence of unauthorized operational changes in disposal practices. Metro proposed the current method of disposal at the meeting and it was approved. Implementation began immediately.

11.6.6 Operation

Sludge disposal began in 1969 and is expected to continue until 1980 giving the site an 11 year life. The site is open 24 hours a day. The area fill operation takes place in locations where the topography is charcterized by rolling hills. Operational considerations are outlined below.

- Sludge to groundwater - 10 to 140 ft (3 to 43 m)
- Soil cover thickness - N/A
- Sludge application - 9,000 yd^3/acre (17,010 m^3/ha)
- Fill depth - 17.5 ft (5 m)
- Sludge exposure - <1 day
- Total soil usage (sludge:soil) - 1:5

11.6.6.1 Site Preparation

Large earthen berms are constructed from soil excavated onsite. The excavation occurs on the top of hills, thus lowering the overall elevation. These berms are constructed in an intersecting orientation, similar to a "tic-tac-toe" configuration. The berms are approximately 20 ft (6 m) in height, several hundred feet in length, and approximately 15 to 20 ft (4.6 to 6 m) in width at the top and are slanted slightly to allow for runoff of water. The berms are constructed in the summer when conditions permit.

11.6.6.2 Sludge Transport

The distance from the sludge source to the disposal site is 26 mi (46 km), one-way. There are 27 to 30 loads delivered daily. Three 1978 Mack Road Tractors and one 1975 IHC Road Tractor are used to haul the sludge and smaller dump trucks handle the sludge on-site. The haul vehicles have a capacity of 40 yd^3 (30 m^3) and the dump trucks hold 13 yd^3 (10 m^3).

The haul vehicles deposit the sludge into sludge storage hoppers at the site. It is then loaded into the smaller dump trucks and delivered to the sludge disposal area.

11.6.6.3 Operational Procedures

The dump truck drives down one berm, turns around, and backs up down the other berm. The configuration or orientation of the berms is such that it cuts down on the length and amount of time needed for backup. The distance that the drivers have to back up is also reduced, which can be important at night and/or when there is inclement weather.

Sludge is dumped from the trucks positioned at the edge of the berm. The dozers located below begin to mix the sludge back and forth between them with the soil from the berm (Figure 11-23). The sludge soil mixture is generally one part sludge to five or six parts soil. As the berm becomes shorter and eventually meets one of the intersecting berms, this intersecting berm then becomes the unloading-working area (Figure 11-23), thus keeping the backup distance to a minimum at all times. Figures 11-24 and 11-25 illustrate equipment used at the landfill.

Once an area has been worked during the winter operation, the following winter's operation occurs on top of that, thus, in effect, burying the sludge-soil mixture of that previous year with the current years' sludge-soil mixture. This layering of each year's mixture combined with excavation of the soil from hilltops has the effect of lowering the hills, filling in low areas, and generally creating a flatter land than was originally present.

FIGURE 11-23

AREA FILL LAYER OPERATION
DENVER, CO

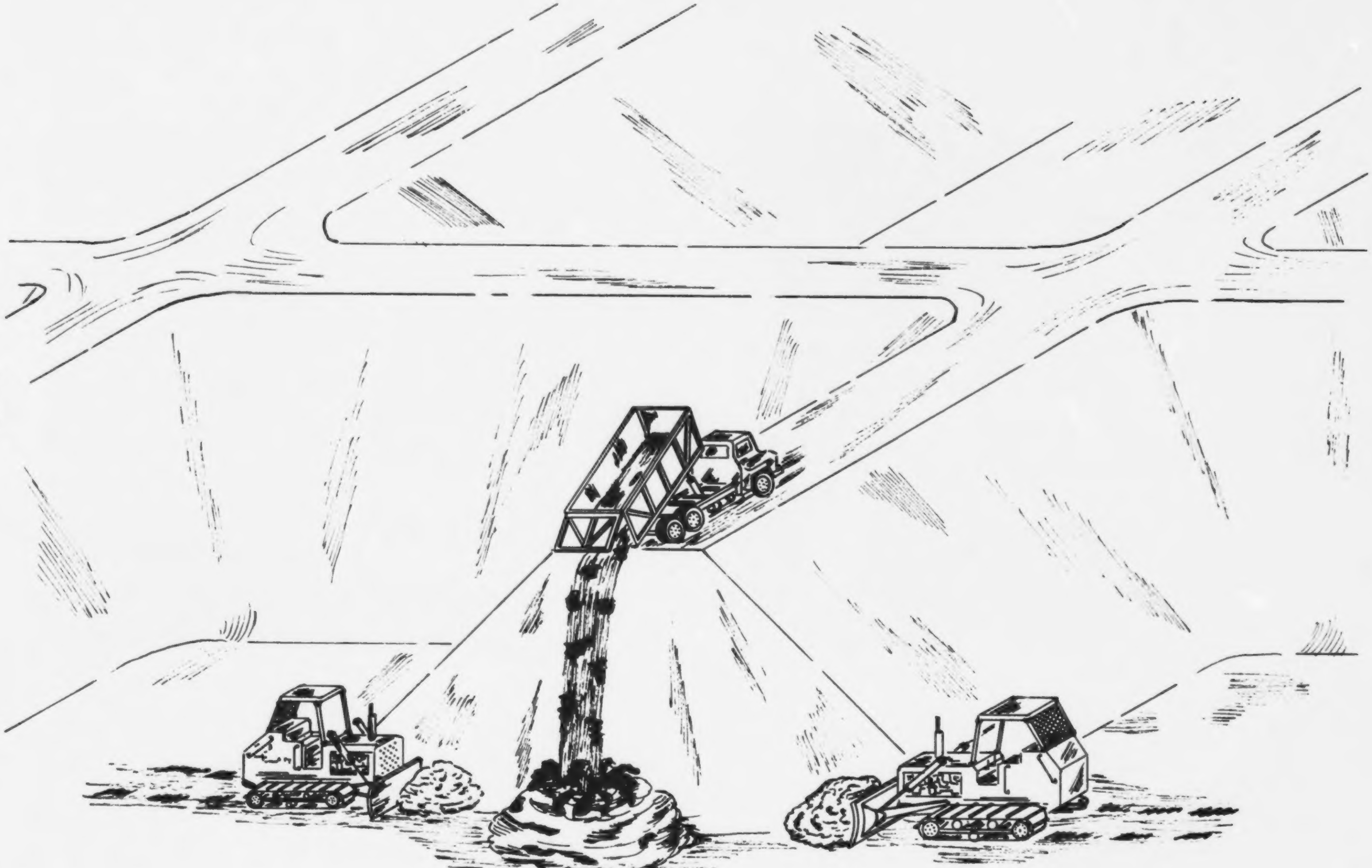


FIGURE 11-24

HAUL VEHICLES
DENVER, CO

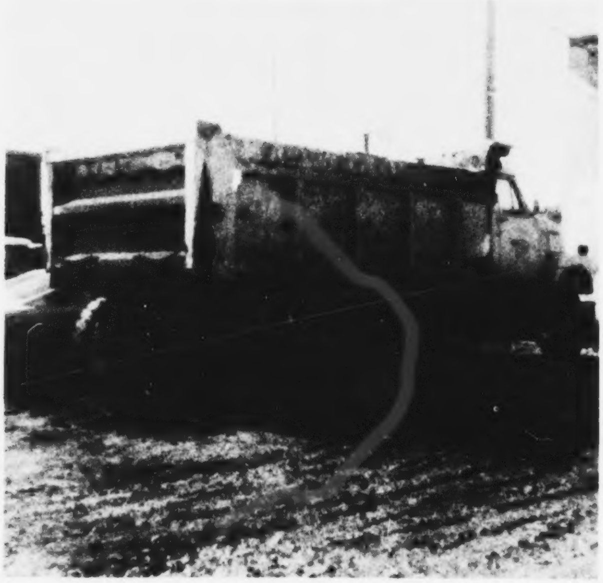


FIGURE 11-25

SLUDGE MIXING EQUIPMENT
DENVER, CO

The following equipment and manpower is used primarily for the sludge landfill operation. However, some of this equipment is also used for the sludge land application that occurs during favorable weather conditions.

Quantity	Description	Purchase Price
1	1977 Dozer, Fiat Allis w/ripper, 21C	$ 132,217
1	1977 Dozer, Fiat Allis, 21C	119,403
1	1977 Grader, Huber, 850	17,600
1	1972 Scraper, Michigan, 210	40,000
1	1977 Front End Loader, Case, W24B	42,985
1	1974 Office Trailer, Elder, 12E797551	4,455
1	1975 Pickup, Dodge, 12E898962	3,286
1	1975 Station Wagon, Plymouth, 12E898961	4,830
1	1977 Pickup, Dodge 4 x 4, 12M84227	4,830
1	1975 Road Tractor, IHC, 12E900075	25,950
3	1978 Road Tractor, Mach, 12M103279-81	32,656/unit
3	1977 Dump Truck, IHC, 12M102631-33	26,860/unit
5	1973 Dump Trailer, Steco, S3270	6,500/unit
21	TOTAL	$ 606,604

Personnel:

Quantity	Job Title
1	Director
1	Environmental Agronomist
1	Field Supervisor
1	Mechanic
10	Field Operators
0.5	Secretary
14.5	TOTAL

11.6.7 Monitoring

In 1974 to 1975, approximately 5 years after disposal began, extensive monitoring of soils, surface and groundwater was initiated in cooperation with the USGS. Samplings are done semi-annually for each.

Two wells are located immediately down slope of the burial areas. Leachate from the sludge appears to be affecting the water quality near the two wells since both exhibit significant deviations from background wells, particularly with regard to nitrates, chloride, ammonia, and magnesium. Moreover, sulfate and manganese concentrations exceeded EPA's recommended drinking water standards.

11.6.8 Costs

The major costs associated with this site are outlined below.

Item	Total Cost ($)	Unit Cost ($/dry tons)
Hauling Cost	(Unknown)	
Site Capital Costs	(Annualized and budgeted for 1978)	
Land	60,000	1.92
Total Capital Cost	60,000	1.92
Site Operating Costs	(Budgeted for 1978)	
Regular wages	349,361	11.19
Overtime wages	19,707	0.63
Materials	45,200	1.45
Fuel, oil & gasoline	60,176	1.93
Outside services	82,410	2.64
Chemicals	4,200	0.13
Electricity	6,420	0.20
Total Site Operating Cost	567,474	18.17
Total Cost	627,474	20.09

The above costs represent the annual combined costs of operating both the landfill and land application operation. Separate cost accounting is not maintained for the two operations and therefore accurate cost figures on the landfill operation alone are not available. However, site operators report that the total annual cost of the landfill operation is the same as the total annual cost of the land application operation despite the fact that the landfill is used an average of only two months (in the winter) each year. At 100 tons per day the site receives 31,285 tons per year (100 t/d x 6d/7d x 365 = 31,285). Assuming then, that half of the total site cost is used for the landfill ($313,737) and that only one-sixth of the total sludge received is attributable to the landfill (5,200 dry tons (4,720 Mg)), the cost of sludge landfilling is $60.33 per dry ton ($66.51/Mg).

11.7 Lorton, Virginia

11.7.1 Background and History

Located off of Interstate I-95, south of Washington, D.C., the Lorton site is a codisposal facility that serves 5 treatment plants (from 4 municipalities) and provides wastewater treatment for approximately 2 million people. The industrial inflow is relatively small since the area is not industrialized. The site handles 58,630 wet tons (53,177 Mg) of sludge per year with an average solids content of 22%. In addition, another 490,000 tons (441,430 Mg) of refuse are dumped each year at the site. Table 11-9 outlines the treatment plants and resulting sludge types that are processed at the site. Although no regulations exist in Virginia that apply directly to sludge disposal, the facility had to receive authorization from the Virginia State Bureau of Solid Waste and Vector Control and the Virginia State Water Control Board before starting operations. Ultimately, permission was granted to dispose of up to 300 tons (272.1 Mg) of sludge per day at the Lorton site. The Washington D.C. federal prison complex is located on the site. Operations began in 1972.

TABLE 11-9

SUMMARY OF SLUDGE GENERATION AND TRANSPORT TO LORTON, VA

	Sludge Generation			Sludge Transport			
Source	Sludge Treatment	Percent Solids	Quantity (wet tons per year)	Vehicle	Capacity Each (tons)	Average Trips Per Day	Haul Distance Miles
Washington (Blue Plains)	Anaerobic Digestion, Dewatering	20%	12,313	Tractor trailers with sealed tailgates	15	4 or 5	20
Alexandria	Anaerobic Digestion, Dewatering	20%	10,554	Tandem-axle dump-trucks with sealed tailgates	7-8	7 to 10	12
Fairfax County	Anaerobic Digestion, Lime and FeCl Addition, Dewatering	20%	34,006	Roll-off containers on small trucks	5	25	8
Arlington County	Incineration	95%	1,759	Tandem-axle dump-trucks with sealed tailgates	7-10	1 or 2	18

1 ton = .907 Mg
1 mi = 1.609 km

11.7.2 Site Description

The site was located at the top of a topographic divide and the slopes were variable. In general, slopes within the actual disposal area did not exceed a 25% grade. The usable area, located near the Lorton prison complex, was free of trees.

Soils in the area had a medium permeability and consisted primarily of fine sands, silt, clay and gravel. The bed rock outcropped frequently in the area of the landfill.

A stream bisected the usable area and cut a valley with a 25% slope. The disposal operations are conducted along the sides of the stream valley. The groundwater varied in depth from 40 to 0 (springs) ft (12.2 to 0 m) below the surface. Springs and streams were protected and culverted in the disposal area.

- Topography - upland with slopes no greater than 25%
- Soil - sand, silt, and clay
- Depth to groundwater - 0 to 40 ft (12.2 to 0 m)
- Groundwater use - the aquifer is not currently used as a source of drinking water
- Freezing days - 85 days/yr
- Precipitation (in.) - 41 in./yr (104 cm/yr)
- Evaporation (in.) - 47 in./yr (120 cm/yr)
- Surface water - stream roughly bisects site

11.7.3 Site Selection

The following factors were important in the site selection process:

- The land was already owned by Wasington, D.C.
- The site size allowed a life of approximately 20 years
- The haul route used interstate roads and other major arteries to within a few miles of the facility.

Since the land was owned by Washington, D.C., the 3,000 ac (1,215 ha) Lorton site was the logical choice for a landfill. Consequently, the selection process consisted largely of evaluating the location. This was an extremely comprehensive investigation and relevant impacts were thoroughly examined.

Evaluation of the facility showed that nearly all aspects of the site were conducive to landfill operations. The factors evaluated included:

- Topography
- Soils
- Geology
- Surface and groundwater

As a result of the investigation, 800 ac (324 ha) were made available for "resource recovery, land reclamation, an d re reation". Of this 290 acre (117 ha) were allocated for land reclamation via sanitary landfilling.

11.7.4 Design

The design criteria employed called for a site life of 18 years. Other design considerations included:

- Adequate Slopes - the slopes had to be steep enough to promote drainage but not so steep that erosion would occur.
- Screening and Buffers - small buffers had to be maintained between the landfill and the prison complex and between the site and roads and residences adjacent to it.
- Groundwater - as a result of investigations conducted by a consulting geologist, it was decided that 2 ft (0.6 m) of natural soil would provide a sufficient buffer between sludge/refuse deposits and the groundwater table. The decision was based on the attenuative properties on the in situ soil.
- Surface Water - upland drainage was diverted around the fill area and on-site streams were protected by installing culverts. Siltation ponds were constructed to contain runoff.

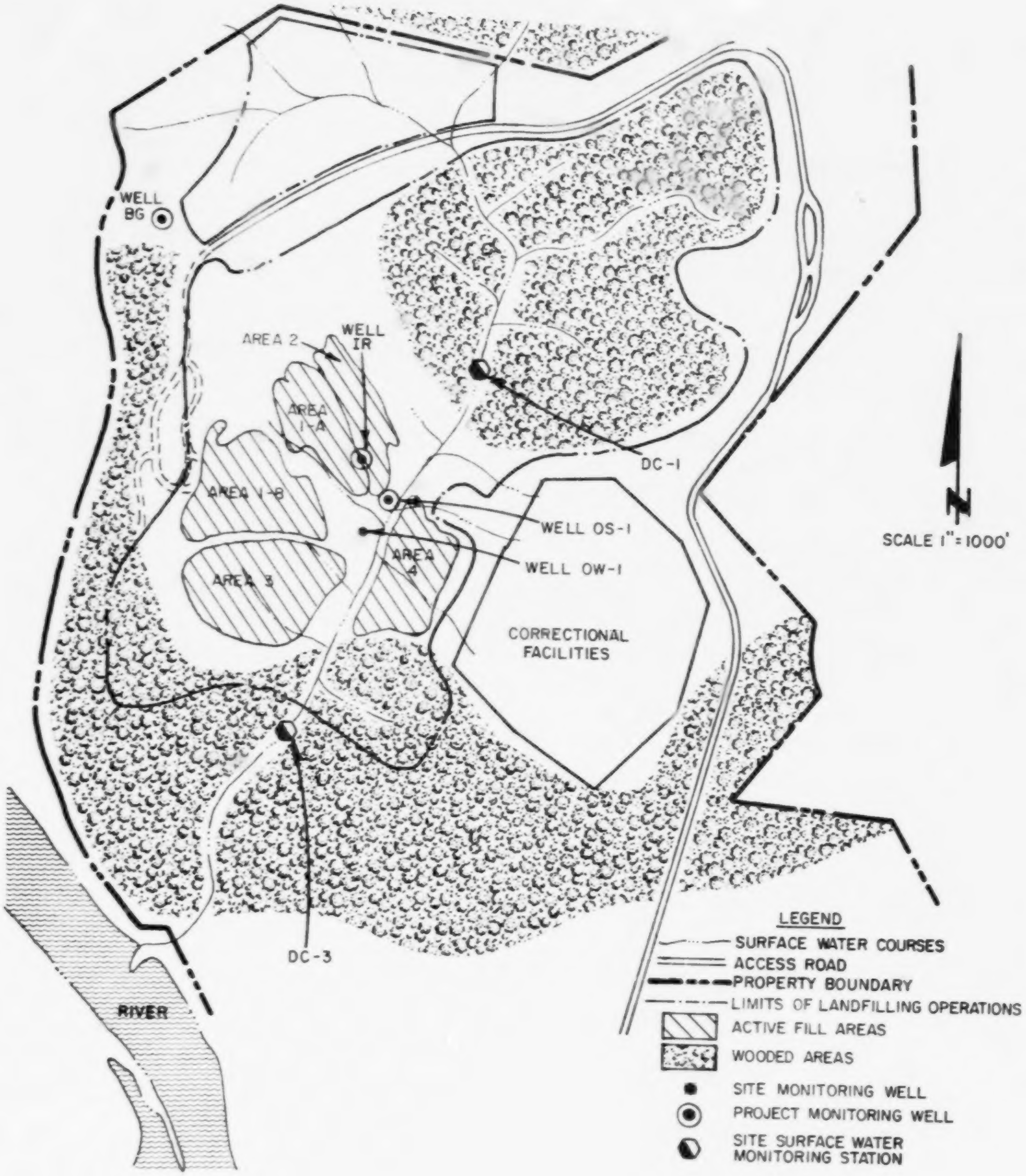
The design identified 20 fill areas that were to be used successively. Clearing and grubbing was performed on the areas only as they were used. In general, the excavation was restricted to the amount needed to provide cover for each segment of the disposal operation. Two phases were established, the first to consist of filling operations along both sides of Mills Branch Creek, the second to be done over the creek's stream valley. Figure 11-26 is a map of the usable areas.

In assessing the amount of soil needed, the design assumed a 20% shrinkage, and a final soil/sludge refuse mix with a 3:1 ratio.

The Lorton facility required both an interim landfill operating permit and a full-scale landfill operating permit. Accordingly, several reports and design plans had to be submitted to the Virginia State Bureau of Solid Waste. These included:

FIGURE 11-26

SITE PLAN LAYOUT
AT LORTON, VA



- A geologic report
- A design report
- A site preparation plan
- A phased fill and covering plan
- An operational procedures report

11.7.5 Public Participiption

11.7.5.1 Public Interaction During Site Approval

Considering the size of the landfill, the amount of refuse and sludge handled, and the fact that much of it comes from outside the jurisdiction of Lorton, public reaction was mild. One explanation for this was that the public was somewhat more preoccupied with the District's penal facility, also located at the Lorton site.

The greatest concern demonstrated by the public was criticism of traffic noise and spilled waste on Furnace Road. There are 5 residences fronting this road on the 3 mi (4.8 km) section connecting I-95 to the disposal site. Noise level investigations were conducted to prove that noise levels were tolerable, but public criticism continued until ultimately a new 3 mi (4.8 km) stretch of road was constructed for the haul vehicles parallel to Furnace Road.

11.7.5.2 On-going Public Relations

Public criticism of the landfill has been continuous, with most complaints centering on odor and spilled refuse. On-site operators have taken steps to accommodate complaints from area residents.

To reduce odors, operators cover the sludge at the operating face daily whenever possible. When sludge is stockpiled over the weekend, masking agents are used. Complaints concerning spilled refuse are handled immediately by on-site crew men. Upon receiving a complaint a crew is dispatched to handle it. It is hoped that this cooperative approach will help to develop a sense of goodwill between the area residents and the landfill operation.

11.7.6 Operation

The site operates 5 days a week from 5 a.m. to 8 p.m. Following is a discussion of the site preparation, hauling, and disposal procedures.

- Sludge to groundwater - 2 ft (0.6 m)
- Soil cover thickness - 0.5 to 2 ft (0.2 to 0.6 m)
- Sludge exposure - <1 day
- Total soil usage (waste:soil) - 1:0.33

11.7.6.1 Site Preparation

Since the landfill occupies the top of a topographic divide no upland drainage flows into the site. All springs and streams on the site are protected by culverts and runoff is collected in on-site basins.

The entire area was surrounded by a chain link fence, electricity was provided for lights on the access roads and operating face; sewer hookups were provided for the weigh station and office.

11.7.6.2 Sludge Transport

The sludge was hauled on interstate I-95 to within 3 mi (4.8 km) of the disposal site. The road was designed to handle heavy trucks and could easily accommodate the impact of increased traffic. A separate access road was constructed to handle traffic from I-95 to the site. The distance from the various treatment plants are summarized in Table 11-9. All roads on-site were paved with asphalt and approached within 1/4 mi (0.4 km) of the operating face.

11.7.6.4 Operational Procedures

Approximately a year before a fill area is to be used it is excavated and grubbed. The operation is basically an area fill and occurs on slopes. Successive sludge/refuse mixtures are layered on the face of the slope and covered with an interim soil cover. Figures 11-27 through 11-30 illustrate the operational procedures described below.

The process starts with refuse being dumped at the toe of a lift and worked uphill. Sludge is then dumped on top of the slope and is worked downhill. The two are then thoroughly mixed (see Figure 11-31). Before closing down for the day 6 in. (15.2 cm) of soil is applied. An interim cover of 12 in. (30.4 cm) of soil is placed when the lift is completed. At the conclusion of phase I filling operations a final 24 in. (60.9 cm) soil cover will be applied.

Originally sludge was not disposed of on the operating face, but was disced into the soil in order to enrich the relatively infertile in situ

FIGURE 11-27

SPREADING SLUDGE OVER REFUSE
LORTON, VA

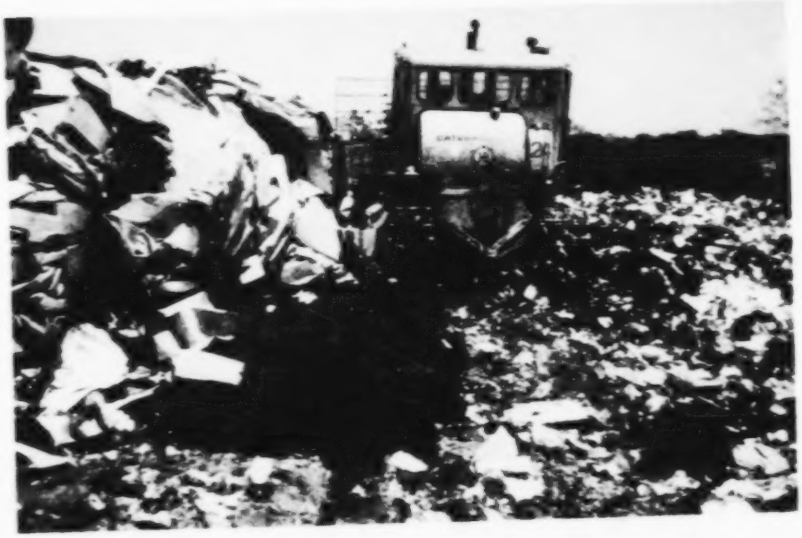


FIGURE 11-28

SLUDGE AT WORKING FACE
LORTON, VA

FIGURE 11-29

COVERING SLUDGE/REFUSE MIXTURE
LORTON, VA

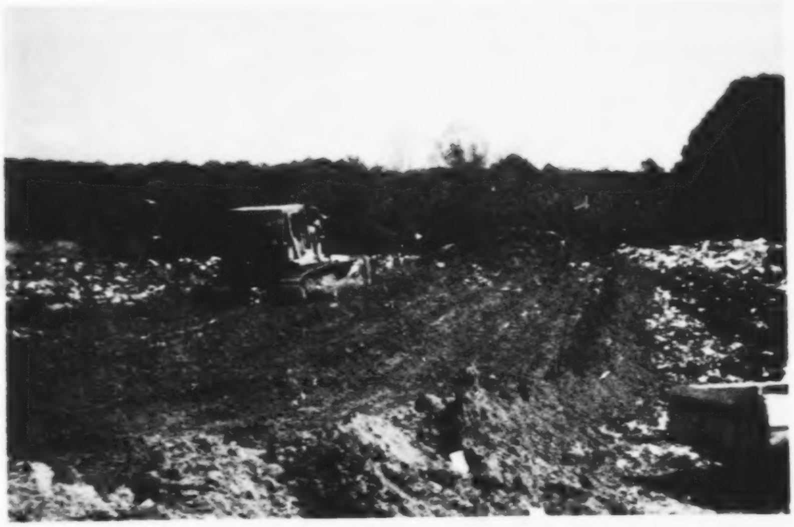


FIGURE 11-30

GRADED SITE
LORTON, VA

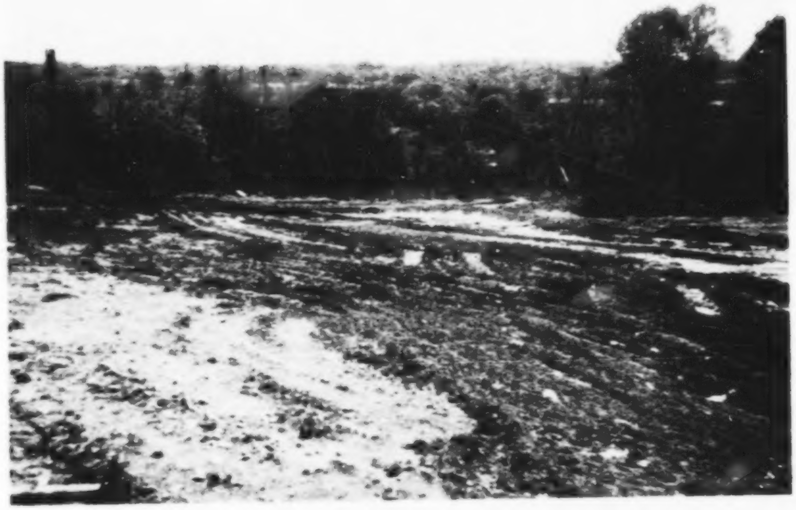
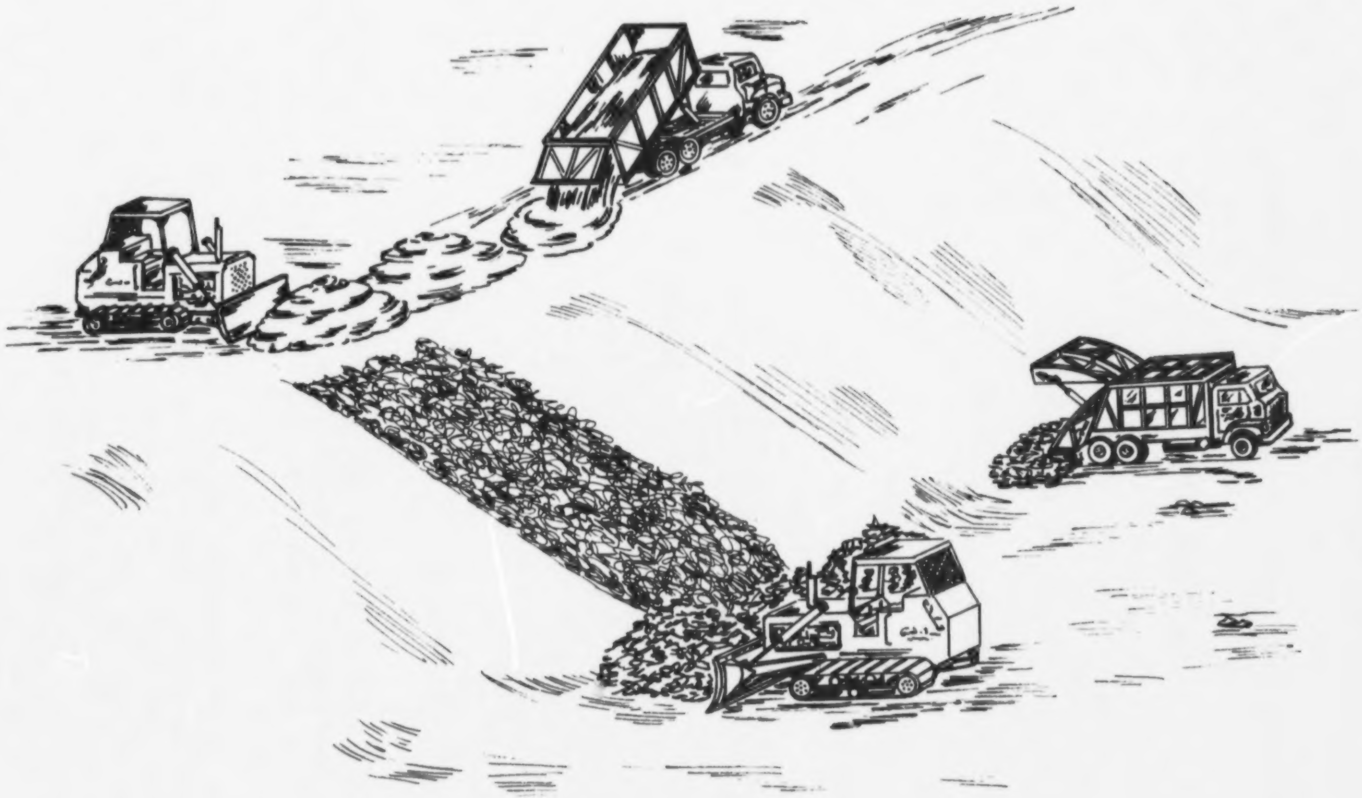


FIGURE 11-31

CODISPOSAL OPERATION
LORTON, VA



soil. However, this practice is not used as frequently since frozen ground and/or unsuitable topography often prevent discing operations. Additional operational features are presented below.

The equipment used in the operation is as follows:

Equipment Type	No.
Landfill Compactor	1
Tracked Bulldozer	5
Scrapers	3
Rubber-tired Front End Loaders	2
Grader	1
Miscellaneous	5
TOTAL	17

Personnel requirements are as follows:

Quantity	Job Title
8	Supervisor
13	Equipment & Truck Operators
18	Laborers
4	Weigh Station Operators
4	Other
47	TOTAL

11.7.7 Monitoring

Monitoring of both surface and groundwater is being conducted at 2 month intervals. Table 11-10 indicates the monitoring parameters used. Figure 11-26 shows the location of gauging stations and test wells.

Surface water monitoring has not detected any additional contamination from the landfill. Readings from the upstream and downstream stations have been consistent. On the other hand, groundwater monitoring revealed that detectable but small amounts of contaminants are leaching from the fill. Lead and iron are the main contaminants monitored in the wells down gradient. Three types of wells are used to monitor groundwater and gas simultaneously.

TABLE 11-10

SAMPLING AND ANALYTICAL PROGRAM AT LORTON, VA

Monitoring Type	Well/Station No.	Sample Collection Technique	Analyses		
			Parameter(s)	Total Times to Date	Frequency
Groundwater	BG US-1	PVC bail sampler	Cd, Cr, Cu, Fe, Hg, Ni, Pb, Zn, Cl, SO_4, TOC	9	every 2 months
Leachate	IR				
Gas	IR	glass burettes	CH_4, CO_2, N_2, O_2	2	every 6 months
Surface Water	DC-1 DC-3	glass bail sampler	Total solids, DO, BOD, Cl, Hardness, Fecal coliform	150	2 times per month
Groundwater	OW-1				

11.7.8 Completed Site

As areas are completed they will be maintained as open space. The completed landfill will be integrated into the surrounding park land and used for recreation.

According to site operators, there has been no appreciable subsidence to date. However, erosion has been a problem and completed areas are regraded and seeded as needed. The current slopes are approximately 25% and it is anticipated that after Phase II is completed the gentler slopes will alleviate the problem of erosion.

11.7.9 Costs

Hauling costs are absorbed by the municipalities contributing sludge to the site. The units are in dollars per wet ton of total solid waste. As shown, total site cost is $4.98 per wet ton of total solid waste. Total site cost per dry ton of sludge is $22.64. Other expenses are presented below.

Capital and operating costs, and total costs are presented below:

	Total Cost ($)	Unit Cost ($/wet ton)
Site Capital Costs (through FY 1978)		
Planning and Design	$ 190,931	$0.06
Road Construction	1,887,495	0.61
Clearing and Grubbing	92,572	0.03
Excavations & Stockpiles	1,169,278	0.38
Truck Weigh Station	684,455	0.21
Equipment	440,446	0.14
Erosion Control & Regrad.	118,141	0.04
Miscellaneous	237,271	0.08
Total Capital Cost To Date	$ 4,820,589	$1.55
Site Operating Costs (for FY 1978)		
Personnel	$ 826,992	$1.61
Equipment Rental	614,488	1.20
Equipment Purchase	8,000	0.02
Equip. Fuel, Parts, Tires	44,000	0.08
Supplies and Materials	176,000	0.34
Utilities	35,600	0.07
Water Testing	10,000	0.02
Miscellaneous	47,000	0.09
Total Site Operating Cost	$ 1,762,080	$3.43
Total Cost (less hauling)	---	$4.98

The unit cost for capital expenditures was determined by establishing the total costs to date and dividing it by the total waste received to date (3,110,000 wet tons (2,820,000 Mg)). Similarly, the operating costs for FY78 were derived by estimating the annual operating expenditures and dividing these costs by the amount of waste anticipated (513,720 wet tons (466,000 Mg)). Operating costs for FY77, for comparison, were $1,508,118.83 and the total tonnage received was 528,207 (480,000 Mg); resulting in a unit cost of $2.86.

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